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# A Semiautomatic AC/DC Thermal Voltage Converter Calibration System

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National Bureau of Standards  
National Engineering Laboratory  
Center for Electronics and Electrical Engineering  
Electrosystems Division  
Washington, DC 20234

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Final Report

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ration Coordination Group



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K. J. Lentner, S. G. Tremaine

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*  
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*



## FOREWORD

The development of the system described in this report was partially funded by the U.S. Department of Defense Calibration Coordination Group (DoD/CCG). Members of the DC and LF Committee were from the Aerospace Guidance and Metrology Center, Newark Air Force Station, Newark, Ohio 43055; the U.S. Army Metrology and Calibration Center, Redstone Arsenal, Huntsville, Alabama 35809; and the Metrology Engineering Center, Bureau of Naval Weapons Representative, Pomona, California 91766.

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In order to adequately describe the system discussed in this report, commercial equipment and instruments are identified by manufacturer's name and model number. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.



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# A SEMIAUTOMATIC AC/DC THERMAL VOLTAGE CONVERTER CALIBRATION SYSTEM

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## Abstract

A semiautomatic ac/dc difference calibration system is described. The system operates over a frequency range of 20 Hz to 100 kHz, covering the voltage range from 0.5 V to 1 kV. For all voltages at frequencies in the range from 20 Hz to 20 kHz, the total uncertainty is 50 parts per million (ppm), and 100 ppm for voltages at frequencies between 20 kHz and 100 kHz. In addition to ac/dc difference testing, the system can be readily adapted to calibrate precision ac digital voltmeters or ac calibrators. Results of extensive intercomparison testing of the new system against a manual test system are reported, using a multirange thermal transfer instrument as a transport standard. The results indicate that the ac/dc differences measured are well within the combined total uncertainty limits of the two systems.

Key words: ac/dc difference; ac voltage measurement; automation; calibration; metrology; thermal voltage converter.

## 1. INTRODUCTION

### 1.1 Objectives

The Semiautomatic AC/DC Thermal Voltage Converter Calibration System, developed at the National Bureau of Standards and described in this report, was designed to use electronic technology to overcome the deficiencies of existing manual test methods. Specific objectives for the new system included: 1) use of commercially available, programmable instruments whenever possible; 2) elimination of the need for manual data entry into a computer for reduction; 3) elimination of the frequent data checks and cross-checks required in manual tests; 4) elimination of as much operator intervention as possible during the test procedure; 5) simplification of necessary remaining interaction by providing displayed operator instruction via computer control; 6) close control of the time interval between application of both ac and dc voltages to the test circuit in order to minimize drift effects; and 7) achievement of the same level of uncertainty as is presently possible with manual testing methods.

### 1.2 Background

Techniques for performing precision ac/dc difference testing, not only at the National Bureau of Standards (NBS), but also in other national and industrial or governmental metrology laboratories, generally make use of manual testing methods which utilize photocell preamplifiers and light-beam galvanometers as voltage detectors in conjunction with manually

balanced voltage comparators [1,2].<sup>1</sup> Careful attention to the elimination or reduction of systematic and random uncertainties in testing methods, range resistors, and thermoelements (TE's) has resulted in sufficient confidence in test data to allow results to be reported with total uncertainties at the 10-100 ppm level (or better, in some cases) over wide voltage and frequency ranges [3,4]. These manual test methods, however, are very time-consuming and subject to errors due to operator fatigue. To overcome these deficiencies, and to expedite test report generation, a semiautomatic ac/dc calibration system was developed.

Because of the low-level dc voltages that must be measured (about 10 nV), large temperature coefficients of TE's, ac or dc source instabilities, and dc reversal differences of TE's, stringent requirements are placed upon the measurement system. In addition, light beam galvanometers suffer the disadvantage of not being easily adaptable to automation. However, with the advent of digital electronics, digital nanovoltmeters are available with sensitivity, resolution, and accuracy sufficient to meet the requirements of precision automatic ac/dc difference testing. Programmable ac and dc voltage calibrators are also available which lend themselves to adaption for automatic testing. Advances in analog/digital interfaces have greatly improved the ease with which computers can be used to control these instruments. The semiautomatic system which evolved is shown in figure 1, and is described in detail in this report. The system operates over a frequency range of 20 Hz to 100 kHz, covering the voltage range from 0.5 V to 1 kV. For all voltages at frequencies in the range from 20 Hz to 20 kHz, the total uncertainty is 50 ppm, and 100 ppm for all voltages at frequencies between 20 kHz and 100 kHz. In addition to ac/dc difference testing, the system can be readily adapted to calibrating precision ac digital voltmeters or ac calibrators. Extensive testing of the new system using a multirange thermal transfer instrument as a transport standard indicates that the test results are well within the reported uncertainty limits. In addition, data obtained with the system indicate that total random uncertainties ( $3\sigma$  limits) of about 3 ppm can be obtained for some ac/dc difference tests.

## 2. TECHNICAL APPROACH

### 2.1 Principle of Operation

A block diagram of the semiautomatic system is shown in figure 2. In principle, the system is similar to the manual system presently used at NBS for routine calibration work, except that overall system control and data acquisition and processing are provided by a 16-bit minicomputer. Programmable ac and dc standards supply the voltages to the thermal converters (consisting of the TE and various range resistors). Such voltage standards are often referred to as ac or dc calibrators. The output voltages of the two converters (as well as the difference between the two voltages) are measured in a semiautomatic mode by means of a

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<sup>1</sup>Numbers in brackets refer to the literature references listed at the end of this report.

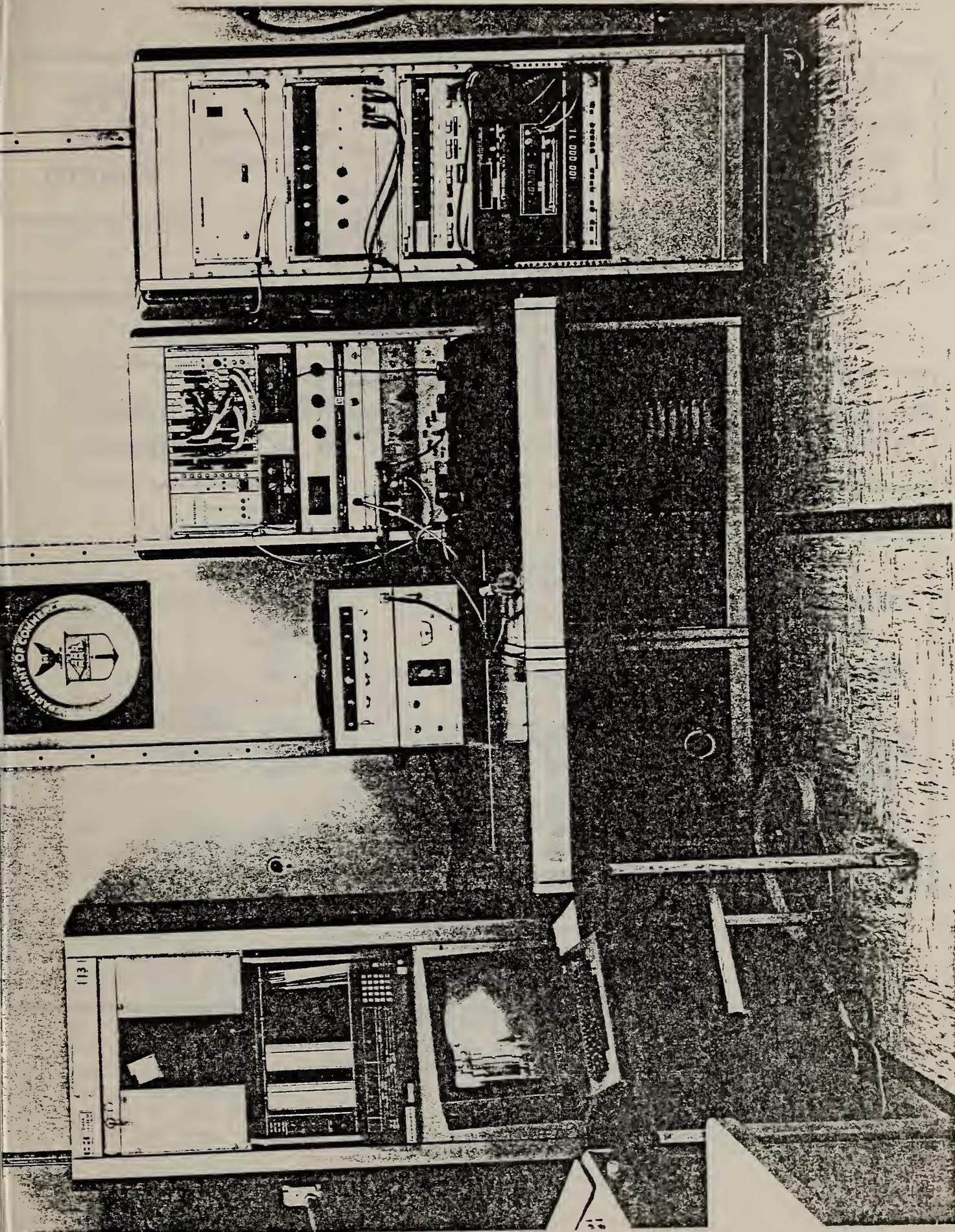


Figure 1. Overall view of system

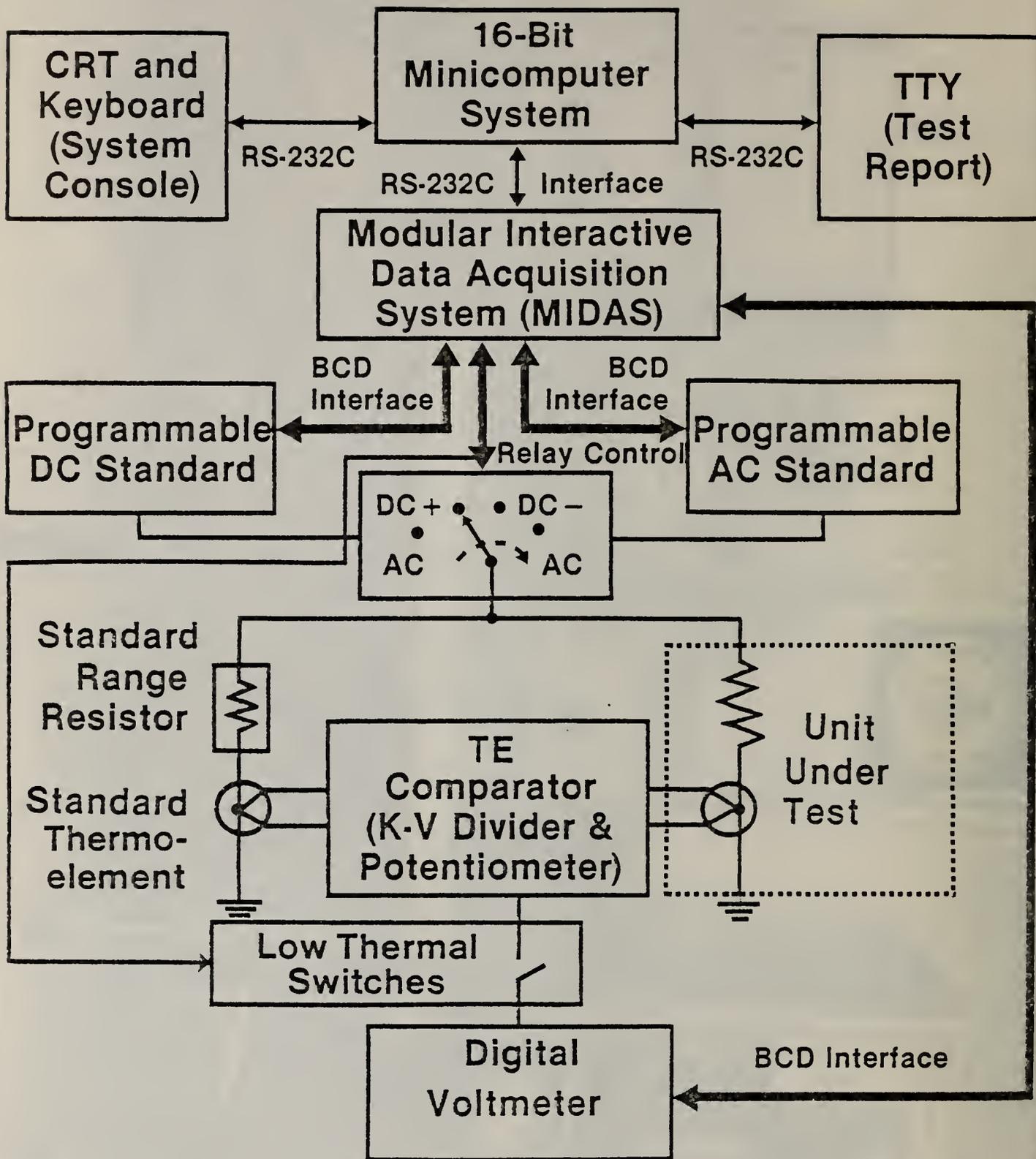


Figure 2. System block diagram

manually operated TE comparator and a digital voltmeter which is automatically controlled via the computer. The computer, its peripheral equipment, and the Modular Interactive Data Acquisition System (MIDAS) [5] are interconnected utilizing the standard RS-232C interface. The programmable instruments and the high voltage and low-thermal-noise switches are controlled by the computer via the MIDAS digital interface.

In operation, the ac or dc voltages are applied simultaneously to the standard TE and the unit under test (UUT). The difference in the output voltages is primarily balanced out by the TE comparator. The small residual differences in the TE output voltages are automatically measured with the digital voltmeter as the inputs are switched between the ac and dc voltages. Typically, the voltage differences are manually balanced to less than 100 nV. The residual voltages are then measured with a resolution of 10 nV, requiring a voltmeter with only moderate accuracy but with low noise. In addition, the voltmeter is used to measure the nominal output voltages of both converters.

## 2.2 Hardware Considerations

### 2.2.1 General

As mentioned previously, the components of the semiautomatic system (except for the computer, its peripheral equipment, and interfaces) are similar to manual systems used at NBS. The principle differences for the new system are the use of a sensitive digital voltmeter and programmable dc and ac voltage standards. A listing of the hardware contained in the system is provided in appendix A.

Overall system control is provided by means of a 16-bit minicomputer which has 64 kbytes of core memory and a dual floppy-disk unit for program and data storage. The system console (CRT), the teletypewriter (TTY), and MIDAS are connected to the computer by means of interfaces which conform to the EIA RS-232-C standard [6]. MIDAS hardware is based on the CAMAC standard [7] and consists of several functional modules which are inserted into slots in an equipment rack. A power supply and MIDAS controller module also are required to make the MIDAS system operational. Communication between the controller module and individual MIDAS modules is in accordance with the ASCII standard code for information interchange [8].

The dc and ac voltage standards must have wide voltage and frequency ranges to meet the requirements of calibration work for which the system is intended. In addition, the standards must be stable and have sufficient resolution to permit precision measurements to be made. The dc voltage standard has ranges of 10 V, 100 V, and 1 kV with resolutions of 1  $\mu$ V, 10  $\mu$ V, and 100  $\mu$ V per step, respectively, with ten steps per range. The specified accuracy is about 30 ppm of range for all three ranges, with output stability of about 15 ppm of programmed output per month. The ac voltage standard has seven decade ranges covering the voltages from 1 mV to 1 kV (full-scale ranges) with a resolution of 10 ppm of range per step, with ten steps per range. The frequency ranges consist

of eleven fixed frequencies per range, covering the range 10 Hz to 110 kHz, with frequency range multipliers of X10 Hz and X100 Hz, X1 kHz and X10 kHz. The accuracy of the ac standard's voltage output varies with frequency, from about 0.02% to 0.05% of voltage setting. The voltage stability is specified as 0.01% of setting for six months.

The digital voltmeter has eight ranges from  $\pm 10 \mu\text{V}$  to  $\pm 100 \text{ V}$ . On the most sensitive  $10 \mu\text{V}$  range, it has a resolution of 10 nV, with an input impedance of about  $10 \text{ M}\Omega$ . The zero stability is specified as less than 100 nV per hour. In the frequency range dc to about 10 Hz, the voltmeter has less than 50 nV of rms noise, referred to the input, with the input shorted.

It should be noted that two digital panel meters used to monitor the outputs of the voltage standards, as well as a frequency counter used to monitor the ac frequency, are not included in figure 2 (for simplicity), but they are visible in figure 1. The large instrument on the left of the test console table (fig. 1) is an ac calibrator under test.

A critical problem in making nanovolt measurements is that of obtaining switches which have low-thermal-noise, and can be controlled automatically. Ideally, TE output voltages of about 10 mV should be measured to within 1 ppm (10 nV). Mercury-wetted contact, self-latching, solid-state and reed relays were found to be unsuitable since these types have thermal-noise on the order of  $1 \mu\text{V}$ . The problem was solved by modifying manually operated low-thermal-noise switches. Solenoids with 24-V operating coils were mechanically linked to such switches. The operating coils are energized by programmable MIDAS relays which connect the 24-V supply to the coils.

The switches which apply the ac or dc voltages to the test circuit are electro-mechanical relays capable of switching up to 5 kV. The 24-V operating coils of these relays also are controlled by MIDAS relays.

### 2.2.2 Measurement Procedures

The various measurement steps will now be explained in some detail for the determination of ac/dc difference, and for determination of the corrections to the nominal output voltages of an ac voltage standard.

A portion of the circuit for ac/dc difference testing, including the components of the TE comparator, is shown in figure 3. The thermal voltage converter (TVC) No. 2 can be either the standard or test converter. The only requirement is that  $E_2$  must be greater than  $E_1$  and, for purposes of this discussion, it is assumed that the test TVC is in the No. 2 position. With rated dc voltage applied, and with the potentiometer (P) turned off, the emf outputs ( $E_2$  of the test unit,  $E_1$  of the standard) are measured by the digital voltmeter (DVM) with switch K2 closed. Another switch in the TE comparator (not shown in fig. 3) permits

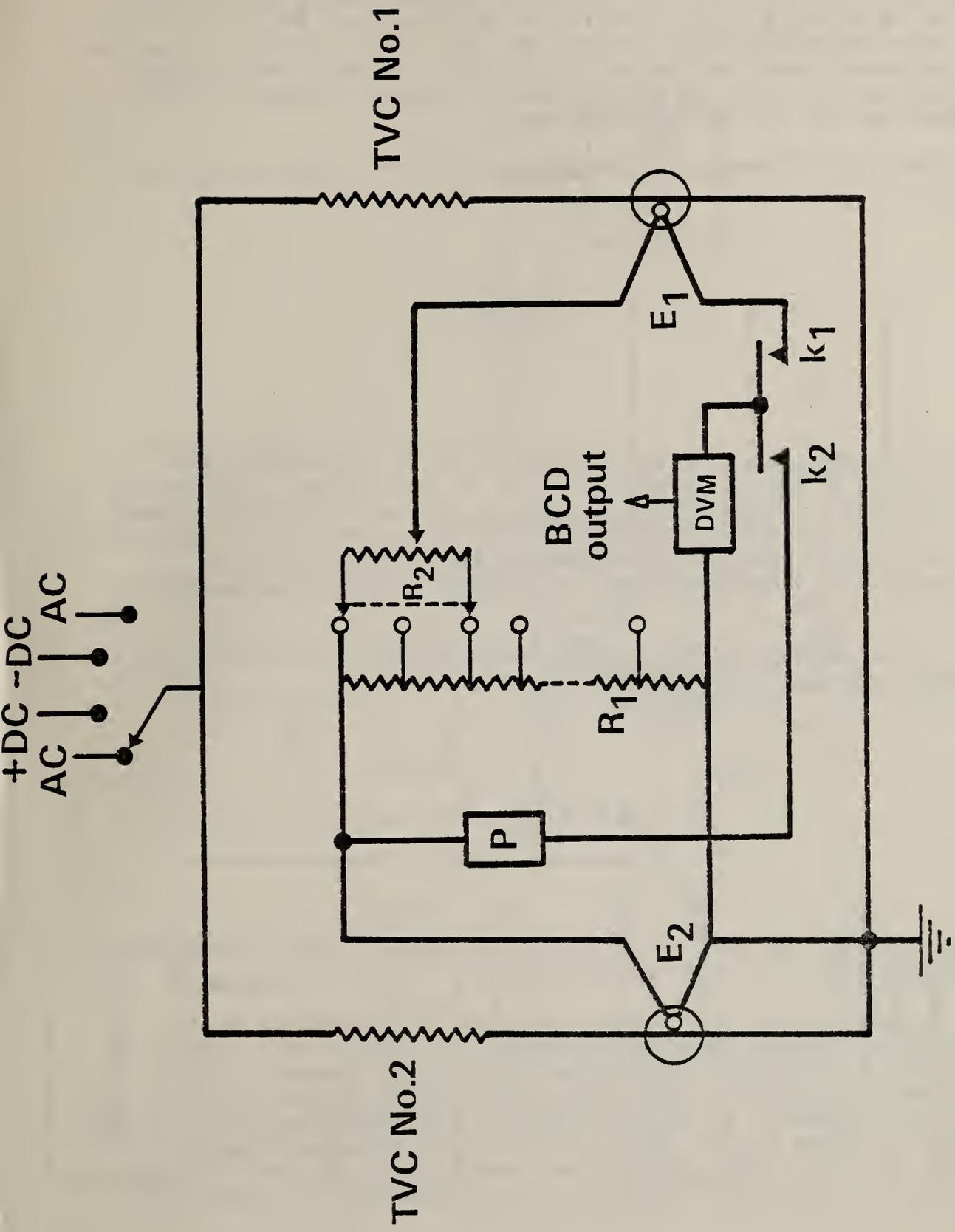


Figure 3. Simplified schematic of thermal voltage converter (TVC) test circuit.

manual selection of either the  $E_2$  or  $E_1$  voltages. With the voltmeter reading  $E_2$ , the potentiometer is adjusted until the voltmeter indicates about 500 nV. Switch K2 is opened, K1 is closed, and the Kelvin-Varley divider is adjusted until the voltmeter indicates about 100 nV. The test then proceeds automatically, and ac, dc+, dc-, and ac voltages are applied (in the order listed) to the test circuit [2]. The difference voltages between the outputs of the test and standard thermal voltage converters are measured for all four input voltages.

The ac/dc difference, in ppm, for the unit under test, as derived in [2], is

$$\delta_t = \delta_s + \frac{E_d - E_a}{n_s E_s},$$

where  $\delta_s$  is the correction to the standard,  $E_d$  is the average emf of the standard TE with two directions of dc voltage applied,  $E_a$  is the emf of the standard TE with ac voltage applied,  $n_s$  is a dimensionless factor ( $< .2$ ) of the standard, and  $E_s$  is the output emf of the standard TE at rated dc voltage input. If  $E_d - E_a$  is measured in nanovolts, and  $E_s$  in millivolts, the expression for  $\delta_t$  is conveniently given in ppm, provided that  $\delta_s$  is in ppm.

If the standard TE has a higher output emf than the test TE, the previous expression is modified to become

$$\delta_t = \delta_s + \frac{E_d - E_a}{n_s E_t},$$

where all terms and units are as previously defined, and  $E_t$  is the output emf of the test TE at rated dc voltage input.

A block diagram of the system when used for calibrating an ac standard or voltmeter is shown in figure 4. As shown in this figure, the system's ac standard is connected for testing. However, the UUT, indicated as "AC STD," could as well be an external ac standard or a precision voltmeter. K1 and K2 are the dc+ and dc- high voltage switching relays, K3 is the ac high voltage relay, and K4 is a low-thermal-noise switch. Using this test circuit, the corrections to the nominal output voltage (at a given dial setting) of an ac standard can be determined

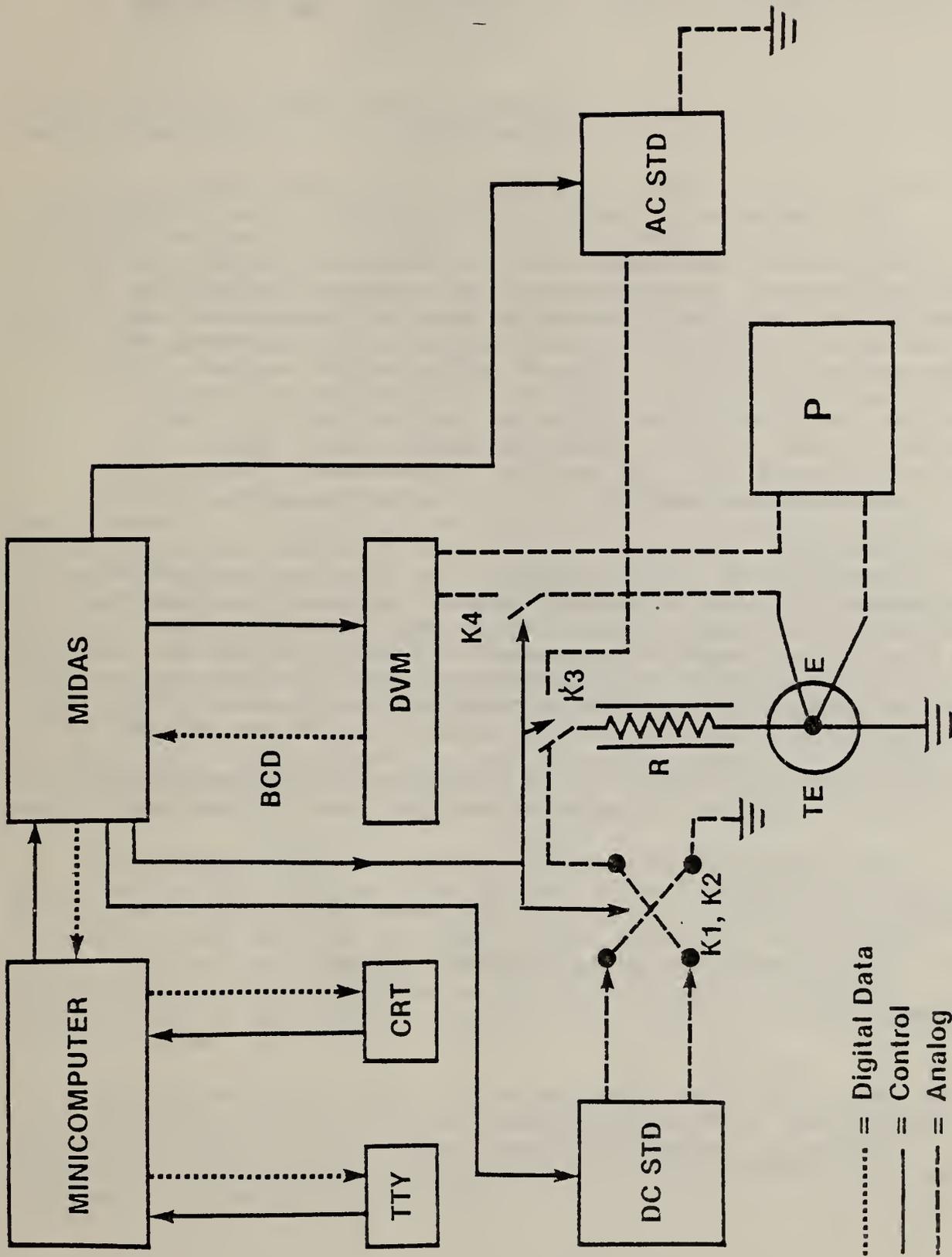


Figure 4. Block diagram of system for calibrating an ac standard or voltmeter

by using the system's programmable dc voltage standard (set to the same nominal value as the ac standard) and a thermal voltage converter, both having known corrections. For this case, only the Lindeck potentiometer (P) of the TE comparator is used. The correction to the UUT, in ppm, is

$$C_t = \delta_s + \frac{E_a - E_d}{nE} + C_{dc},$$

where  $\delta_s$  is the ac/dc difference correction (in ppm) of the TVC at the test frequency,  $E_a$  is the reading of the voltmeter (DVM) with ac voltage applied (i.e., the difference between the TE's output emf and the fixed voltage of the Lindeck potentiometer),  $E_d$  is the average of the DVM readings with direct voltage of both polarities applied,  $n$  is a dimensionless factor equal to 2 if the TE has a square-law response,  $E$  is the TE's output emf at the applied test voltage, and  $C_{dc}$  is the correction (in ppm) to the dc voltage standard's nominal output. As for ac/dc difference tests, the equation is conveniently given in ppm if  $E_a - E_d$  is in nanovolts and  $E$  is in millivolts, with  $\delta_s$  and  $C_{dc}$  also in ppm.

The denominator of the correction equation contains the dimensionless characteristic "n." Most TE's do not have an ideal square-law response, hence, the value of  $n$  must be determined. Since  $n$  generally ranges in value from 1.6 to 2, neglecting to measure a TE's actual value of  $n$  can lead to significant errors in the correction to the UUT. For example, in the worst case, if  $n$  is assumed to be 2, but actually is 1.6, then the error amounts to  $(2-1.6)/(2) = 0.2$ , or 20 percent of the correction.

The procedure for measuring  $n$  (to a first order of approximation) is based on the fact that a TE's output voltage ( $E$ ) can be expressed as

$$E = kI^n,$$

where  $I$  is the current through the TE's heater element.

Therefore,

$$dE = knI^{n-1} dI,$$

and 
$$dE/E = (knI^{n-1} dI)/(kI^n).$$

Hence, 
$$dE/E = n(dI/I),$$

and, assuming constant heater resistance and a stable voltage source,

$$dE/E \approx n(dV/V),$$

where  $V$  is the dc voltage applied across the series combination of a range resistor and a TE.

Two techniques can be used to measure the characteristic  $n$ . One involves making small, accurately known changes in the voltage ( $\Delta V$ ). The second involves making changes in the TE's heater current ( $I$ ) with the applied voltage held constant. In the second method, which is used for the MIDAS-based system, small changes in the heater current through the TE under test are obtained when a 400  $\Omega$  resistor, in series with a 40 k $\Omega$  range resistor, is shorted by closing a MIDAS relay.

## 2.3 Software Considerations

### 2.3.1 General

In order to reduce the effort involved in making routine tests, the software for the system was designed to provide as much interaction between the system console and the operator as possible. This interaction is used to reduce the possibility of damage to either the standard or UUT when either software or hardware failures occur. Also, by progressing logically through the initialization portions of the test routines, the operator, when necessary, can take whatever corrective actions might be required. A significant advantage of the resulting software design is that sufficient warm-up time is automatically provided between application of the various test voltages so that the effects of errors due to the warm-up drifts of the standard and test units are reduced. In addition, the computer closely controls the time intervals between voltmeter readings; hence, the effects of linear drift are minimized.

The programs, which are written in BASIC, provide the means for automatically setting the ac or dc voltages and ac frequency, operating the voltage relays and low-thermal-noise switches, triggering the voltmeter to obtain voltage readings, and storing these readings in the computer memory. Six programs constitute the major testing software package. Program ACDCLV is used for making ac/dc difference tests at voltages from 0.5 to 95 V, and ACDCHV is used for similar tests at voltages greater than 105 V up to 1 kV.

Since the major application of the work described in this report is ac/dc difference testing, a typical sequence of operations for this type of testing is described below where the ACDCHV program is discussed. The other five programs will only be mentioned briefly; however, detailed information is available upon request.

ACDCHV is a program which provides partial automatic control of ac/dc difference testing at voltages greater than 105 V. Since the MIDAS interface does not have isolated analog and digital grounds, it was necessary to develop a separate software package for high-voltage testing. At high voltages, it was found that operating either the ac or dc voltage relays introduced transient voltage surges into the MIDAS digital circuitry. The MIDAS controller interpreted these surges as voltage level changes identical to programmed commands. The result was that incorrect relays might be opened or closed, the voltmeter might be falsely triggered to obtain a reading, or any other of a series of unwanted events might occur. Hence, the ACDCHV program was developed to ensure that no high-voltage standards are turned on whenever a voltage relay is operated. To avoid unnecessary operation of the high-voltage relays, program ACDCLV should be used for tests below 100 V.

Basically, ACDCHV contains three general sections. At the beginning, test documentation (e.g., date, test number, observer, and instrument) is requested. String and array variables are dimensioned, and various simple variables are initialized. A heading for the test documentation is created by the operator. The midsection includes a network of subroutines that interact with the operator. Displayed instructions prompt the operator to define test parameters for setting ac and dc voltages, to switch the TE comparator from E-high to E-low, and to initially balance the Kelvin-Varley divider and rebalance it when necessary. Repeatedly accessed subroutines close and open the appropriate relays, set the input voltages, determine the TE emf output voltages, trigger the voltmeter to read the TE difference voltages, and calculate the ac/dc difference of the UUT for four determinations at each test point. Finally, statistical calculations are performed and the results are printed on the TTY. Options are then provided for the operator to choose whether to stop, repeat a test with or without averaging, or change parameters and run another test.

Program NTSTF is used to determine a TE's dimensionless factor,  $n$  [1,2]. The variation of  $n$  as a function of a TE's heater current can be expressed as  $n = g(E)$ , and this function is assumed to vary linearly. The program automatically fits a least-squares line to the data. The computational techniques used are fully discussed on pages 5-10 of [10]. Typical test results are illustrated in table 1.

Table 1. N-Test-F data

|                |                   |        |                |       |        |                  |       |       |
|----------------|-------------------|--------|----------------|-------|--------|------------------|-------|-------|
| DATE . . . . . | THUR. 29 MARCH 79 |        |                |       |        | OBSERVER. . .KJL |       |       |
| TEST NO. . . . | N-TEST            |        | INST NO. . .FA |       |        |                  |       |       |
| VOLTS          | E                 |        | N              |       |        | AVE.N            | NE    | 500/N |
| 100            | 2.70              | (1.992 | 1.991          | 1.990 | 1.990) | 1.991            | 5.37  | 251.2 |
| 100            | 2.70              | (1.988 | 1.988          | 1.989 | 1.991) | 1.990            | 5.37  | 251.3 |
| 120            | 3.88              | (1.973 | 1.973          | 1.974 | 1.975) | 1.974            | 7.66  | 253.3 |
| 120            | 3.88              | (1.973 | 1.974          | 1.975 | 1.975) | 1.974            | 7.66  | 253.3 |
| 140            | 5.24              | (1.954 | 1.955          | 1.956 | 1.956) | 1.955            | 10.25 | 255.7 |
| 140            | 5.24              | (1.954 | 1.955          | 1.957 | 1.956) | 1.955            | 10.25 | 255.7 |
| 160            | 6.79              | (1.922 | 1.923          | 1.925 | 1.923) | 1.923            | 13.06 | 260.0 |
| 160            | 6.79              | (1.922 | 1.923          | 1.924 | 1.923) | 1.923            | 13.06 | 260.0 |
| 180            | 8.50              | (1.881 | 1.881          | 1.883 | 1.882) | 1.882            | 16.00 | 265.7 |
| 180            | 8.50              | (1.878 | 1.881          | 1.883 | 1.882) | 1.881            | 15.99 | 265.8 |
| 200            | 10.34             | (1.833 | 1.833          | 1.835 | 1.833) | 1.833            | 18.96 | 272.7 |
| 200            | 10.34             | (1.826 | 1.832          | 1.834 | 1.834) | 1.833            | 18.95 | 272.8 |

THE CURVE FITTING PROCESS USES A LEAST-SQUARES FIT FOR A POLYNOMIAL OF DEGREE ONE. THE N (LOWER CASE) TE CHARACTERISTIC (Y-AXIS) VERSUS TE EMF (X-AXIS) IS ASSUMED TO BE A LINEAR FUNCTION OF THE FORM  $Y = B+MX$  OR, IN THIS CASE:

$$NI = M-NE$$

WHERE NI = TE CHARACTERISTIC

M = ZERO X INTERCEPT

N = NEGATIVE OF CURVE SLOPE

E = TE OUTPUT EMF

$$M = . . . . . 2.05518$$

$$N = . . . . . .206568E-1$$

ACCAL is a program used to calibrate an ac voltage standard, a precision ac digital voltmeter, or the ac standard of the system in terms of a thermal voltage converter and the system's calibrated dc standard, as discussed in the previous section. Results for the calibration of an ac voltage standard are illustrated in table 2. The last column, "T CORR PPM," shows the correction to the calibrator's nominal output voltage.

Stability of the system's dc and ac standards can be checked by using programs called STABLV and STABHV. These programs are used for voltage ranges similar to those for ACDCLV and ACDCV. Occasionally, test results appear to be erratic. These stability tests are useful in determining if the supplies are functioning properly. Stability of the sources is measured by using a programmable 6-1/2 digit multimeter whose function, ranges, and reading rates are remotely controlled. Initial stability test parameters for voltage, frequency, time between readings, and total number of readings are defined by the operator. The program then exercises automatic control over the ac and dc standards, the voltage relays, and the voltmeter. At completion, stability data including the values of minimum, maximum, range, average, standard deviation of the mean, and three times the standard deviation of the mean (calculated  $3\sigma$  limits) for both ac and dc voltage readings are printed on the TTY. Table 3 shows the results of a test at 95 V, 50 kHz, with the voltmeter programmed to use a 10-second integration time. The total time for the test illustrated was about 12 minutes, which is about the time it takes to do a test run (i.e., four determinations) for ac/dc difference tests at one frequency and voltage.

The advantages of the stability tests are illustrated in table 4. The difference in the ranges of the ac voltage for tests at 95 V and 200 V indicates that the ac high-voltage amplifier had become unstable. The instability was verified by a 12-minute test in which the ac voltage range was about 1150 ppm at 20 V as opposed to about 347 ppm at 95 V.

In addition to the test capabilities discussed above, the methodology and computer programs were developed for testing one model of a precision multirange automatic thermal transfer instrument as a voltmeter. Detailed information is available and can be supplied upon request.

### 2.3.2 Operating Procedure for AC/DC Difference Tests

For the reader not interested in the operational details of this program (contained in appendix B), the following overview is provided. The specific operating procedures include the following steps and instructions:

- 1) Input via the system console, the test number, voltage, frequency, observer's name, and code for the standard thermal converter.
- 2) Visually check to see that both software and hardware are operating correctly by checking the system's digital panel meters and frequency meter for correct readings of the outputs from the ac and dc standards. If the outputs are incorrect, repeat step 1.

Table 2. ACCAL data

DATE. . . . . OBSERVER. . . . .  
 TEST NO . . . . . INST. . . . .

| KHZ | CORR PPM | V     | TEST RANGE | STANDARD TE | RANGE | E MV | NE   | T CORR PPM |
|-----|----------|-------|------------|-------------|-------|------|------|------------|
|     |          | 100.0 | 100.0      | FB          | 100.0 | 10.4 | 18.6 |            |
| 0.8 | 0        |       | (7 8       | 7           | 10)   |      |      | -8         |
| 0.8 | 0        |       | (7 6       | 7           | 3)    |      |      | -7         |
| 0.8 | 0        |       | (7 8       | 8           | 3)    |      |      | -7         |
| 0.8 | 0        |       | (5 1       | 4           | 3)    |      |      | -6         |
| 2.4 | 0        |       | (29 32     | 33          | 33)   |      |      | 32         |
| 2.4 | 0        |       | (30 35     | 34          | 35)   |      |      | 33         |
| 2.4 | 0        |       | (32 35     | 25          | 38)   |      |      | 33         |
| 2.4 | 0        |       | (31 31     | 32          | 35)   |      |      | 33         |
| 4.8 | 0        |       | (278 282   | 281         | 284)  |      |      | 281        |
| 4.8 | 0        |       | (278 284   | 284         | 283)  |      |      | 282        |
| 4.8 | 0        |       | (278 284   | 284         | 285)  |      |      | 282        |
| 4.8 | 0        |       | (281 283   | 285         | 283)  |      |      | 283        |
| 0.4 | 0        |       | (11 13     | 10          | 9)    |      |      | 11         |
| 0.4 | 0        |       | (3 8       | 9           | 8)    |      |      | 8          |
| 0.4 | 0        |       | (5 8       | 9           | 9)    |      |      | 8          |
| 0.4 | 0        |       | (5 9       | 11          | 8)    |      |      | 8          |

Table 3. Low voltage stability test data

| READING    | DC-VOLTAGE | PPM  | AC-VOLTAGE | PPM     |
|------------|------------|------|------------|---------|
| NO. 1      | 95.00530   | 55.9 | ****       | ****    |
| NO. 1 (A)  | ****       | **** | 94.51200   | -5136.9 |
| NO. 2      | 95.00530   | 55.9 | ****       | ****    |
| NO. 2 (A)  | ****       | **** | 94.51300   | -5126.3 |
| NO. 3      | 95.00530   | 55.9 | ****       | ****    |
| NO. 3 (A)  | ****       | **** | 94.51200   | -5136.9 |
| NO. 4      | 95.00540   | 56.5 | ****       | ****    |
| NO. 4 (A)  | ****       | **** | 94.51200   | -5136.9 |
| NO. 5      | 95.00530   | 55.9 | ****       | ****    |
| NO. 5 (A)  | ****       | **** | 94.51200   | -5136.9 |
| NO. 6      | 95.00530   | 55.9 | ****       | ****    |
| NO. 6 (A)  | ****       | **** | 94.51100   | -5147.4 |
| NO. 7      | 95.00510   | 54.0 | ****       | ****    |
| NO. 7 (A)  | ****       | **** | 94.51000   | -5158.0 |
| NO. 8      | 95.00510   | 54.0 | ****       | ****    |
| NO. 8 (A)  | ****       | **** | 94.50800   | -5179.0 |
| NO. 9      | 95.00520   | 54.6 | ****       | ****    |
| NO. 9 (A)  | ****       | **** | 94.50700   | -5189.4 |
| NO. 10     | 95.00510   | 54.0 | ****       | ****    |
| NO. 10 (A) | ****       | **** | 94.50700   | -5189.4 |

DC

| NO. OF READINGS | MEAN (PPM) | STAN. DEV. OBSERVATION | STAN. DEV. MEAN | STAN. DEV. MEAN *3 |
|-----------------|------------|------------------------|-----------------|--------------------|
| 10              | 55.3       | 1.0                    | 0.3             | 1.0                |
| MIN = 53.9679   |            | MAX = 56.5378          |                 | RANGE = 2.5699     |

AC

| NO. OF READINGS | MEAN (PPM) | STAN. DEV. OBSERVATION | STAN. DEV. MEAN | STAN. DEV. MEAN *3 |
|-----------------|------------|------------------------|-----------------|--------------------|
| 10              | -5153.7    | 23.9                   | 7.5             | 22.6               |
| MIN = 5189.43   |            | MAX = -5126.31         |                 | RANGE = 63.1211    |

V-NOMINAL 95      FREQUENCY 50 KHZ      INT. TIME 10 SEC      TIME DELAY 10

Table 4. Stability test data summary  
 Program: STABLV - Overnight (17 hr) Test

| DC              | Mean  | Stan. Dev.    | Stan. Dev. | Stan. Dev.      |
|-----------------|-------|---------------|------------|-----------------|
| No. of Readings | (PPM) | Observation   | Mean       | Mean *3         |
| 50              | 42.1  | 5.0           | 0.7        | 2.1             |
| Min = 36.7817   |       | Max = 56.5378 |            | Range = 19.7561 |

| AC              | Mean  | Stan. Dev.    | Stan. Dev. | Stan. Dev.      |
|-----------------|-------|---------------|------------|-----------------|
| No. of Readings | (PPM) | Observation   | Mean       | Mean *3         |
| 50              | 216.6 | 51.0          | 7.2        | 21.6            |
| Min = 84.1643   |       | Max = 431.583 |            | Range = 347.419 |

| V-Nominal | Frequency | Int. Time | Time Delay |
|-----------|-----------|-----------|------------|
| 95        | 1 kHz     | 10 sec    | 57500      |

Program: STABHV - Overnight (17 hr) Test

| DC              | Mean  | Stan. Dev.   | Stan. Dev. | Stan. Dev.      |
|-----------------|-------|--------------|------------|-----------------|
| No. of Readings | (PPM) | Observation  | Mean       | Mean *3         |
| 50              | 17.1  | 2.7          | 0.4        | 1.1             |
| Min = 9.99451   |       | Max = 19.989 |            | Range = 9.99451 |

| AC              | Mean     | Stan. Dev.   | Stan. Dev. | Stan. Dev.      |
|-----------------|----------|--------------|------------|-----------------|
| No. of Readings | (PPM)    | Observation  | Mean       | Mean *3         |
| 50              | -4168.96 | 428.0        | 60.5       | 181.6           |
| Min = -25400    |          | Max = -23450 |            | Range = 1949.99 |

| V-Nominal | Frequency | Int. Time | Time Delay |
|-----------|-----------|-----------|------------|
| 200       | 50 kHz    | 10 sec    | 3000       |

Program: STABHV - 12 Minute Test

| DC              | Mean  | Stan. Dev.    | Stan. Dev. | Stan. Dev. |
|-----------------|-------|---------------|------------|------------|
| No. of Readings | (PPM) | Observation   | Mean       | Mean *3    |
| 10              | 10.0  | 0.0           | 0.0        | 0.0        |
| Min = 9.99451   |       | Max = 9.99451 |            | Range = 0  |

| AC              | Mean    | Stan. Dev.   | Stan. Dev. | Stan. Dev.      |
|-----------------|---------|--------------|------------|-----------------|
| No. of Readings | (PPM)   | Observation  | Mean       | Mean *3         |
| 10              | -3890.0 | 433.9        | 137.2      | 411.6           |
| Min = -24750    |         | Max = -23600 |            | Range = 1149.98 |

| V-Nominal | Frequency | Int. Time | Time Delay |
|-----------|-----------|-----------|------------|
| 200       | 50 kHz    | 10 sec    | 5          |

3) Manually set the TE comparator to its "high TE" voltage input position, and switch the voltmeter to its 10-mV range. The program automatically closes the dc voltage relay and a low-thermal-noise switch (K2) turns on the dc standard and triggers the voltmeter to obtain the TE voltage output reading.

4) Switch the TE comparator to its "low TE" voltage input position. The program then triggers the voltmeter to read the voltage. The values of the high- (from the previous step) and low-voltage readings are compared. If the latter is actually larger in magnitude than the former, the operator is instructed to interchange the two TE inputs after the dc voltage has been turned off. The program automatically stores the correct value of E-low, since that value is used in the equation to determine the ac/dc difference of the test unit (see section 2.2).

5) Switch the TE comparator to the "high TE" voltage input position. This step in the procedure is done only if the test unit actually has a greater emf output than the standard. If not, the comparator switch remains in the "low TE" voltage input position. In either event, the operator is then instructed to turn on the Lindeck potentiometer, change the voltmeter to its 10  $\mu$ V range, and manually adjust the potentiometer until the voltmeter indicates about 500 nV.

6) Switch K2 is opened, and a second low-thermal noise-switch (K1) is closed. The operator now manually adjusts the Kelvin-Varley divider until the voltmeter indicates a voltage within the range  $\pm 100$  nV.

7) Switch K1 is opened, K2 closed, the ac voltage relay is closed, the ac standard turned on, and its voltage is automatically incremented or decremented until the output voltage of the UUT's TE is  $\leq 1$   $\mu$ V of its value with dc voltage applied, as in step 6.

8) At this point, the manual initialization process is complete, switch K2 is opened, K1 is closed, and the test proceeds automatically under program control. A sequence of voltage readings is obtained by the voltmeter when ac, dc+, dc-, and ac voltages are applied to the standard thermal voltage converter and UUT. These four voltage readings are each obtained from the average of ten readings of the voltmeter. The standard deviation of the ten readings is computed, and if this value is  $< 200$  nV, the program continues. If the standard deviation is  $\geq 200$  nV, due to drifts in either the standard converter or the UUT, or the ac or dc standards, or any of these effects combined, the series of ten readings is repeated. After five attempts, if the voltmeter readings have not stabilized, the test is aborted.

9) The sequence of readings with ac, dc+, dc-, and ac voltages applied constitutes one determination of the ac/dc correction to the UUT. The process is continued for four determinations; the average value of four determinations is computed and printed. The operator then may elect to repeat the test, change voltage range or frequency, or stop the test. A sample of data printed on the teletypewriter is illustrated in table 5. Although only low-voltage test results are shown, the data format is identical for high-voltage tests.

Table 5. AC/DC difference data

DATE.....10/18/78  
 OBSERVER.....BC  
 TEST NO.....NBSTES  
 INST.....FA50

|       | APP<br>V | RANGE | STANDARD<br>TE RANGE | ES<br>MV | ET<br>MV | NSEL<br>N*MV |      |         |
|-------|----------|-------|----------------------|----------|----------|--------------|------|---------|
|       | 30.0     | 50.0  | FD 100.0             | 4.5      | 3.3      | 6.40         |      |         |
| kHz   | COR      |       | AC/DC DIFFERENCE     |          |          |              | STD  | AVE T   |
|       | PPM      |       |                      |          |          |              | DEV  | COR PPM |
| 50.0  | -2       |       | ( 273 279            | 280      | 277)     |              | 3.2  | 275.3   |
| 50.00 | -2       |       | ( 275 282            | 281      | 289)     |              | 4.9  | 277.5   |
|       | 30.0     | 50.0  | FD 100.0             | 4.5      | 3.2      | 6.38         |      |         |
| kHz   | COR      |       | AC/DC DIFFERENCE     |          |          |              | STD  | AVE T   |
|       | PPM      |       |                      |          |          |              | DEV  | COR PPM |
| 20.00 | 0        |       | ( 100 121            | 105      | 100)     |              | 9.7  | 106.4   |
| 20.00 | 0        |       | ( 102 107            | 110      | 117)     |              | 7.6  | 107.6   |
| 20.00 | 0        |       | ( 97 101             | 106      | 105)     |              | 7.0  | 105.7   |
|       | 50.0     | 50.0  | FD 100.0             | 11.2     | 8.4      | 14.92        |      |         |
| kHz   | COR      |       | AC/DC DIFFERENCE     |          |          |              | STD  | AVE T   |
|       | PPM      |       |                      |          |          |              | DEV  | COR PPM |
| 50.00 | -2       |       | ( 278 280            | 279      | 279)     |              | 1.1  | 277.1   |
| 50.00 | -2       |       | ( 280 280            | 280      | 281)     |              | 1.0  | 277.7   |
| 50.00 | -2       |       | ( 285 285            | 284      | 286)     |              | 2.7  | 279.4   |
|       | 50.0     | 50.0  | FD 100.0             | 11.2     | 8.4      | 14.92        |      |         |
| kHz   | COR      |       | AC/DC DIFFERENCE     |          |          |              | STD  | AVE T   |
|       | PPM      |       |                      |          |          |              | DEV  | COR PPM |
| 20.00 | 0        |       | ( 106 109            | 106      | 105)     |              | 1.6  | 106.4   |
| 20.00 | 0        |       | ( 107 104            | 105      | 106)     |              | 1.4  | 106.0   |
|       | 50.0     | 50.0  | FD 100.0             | 11.2     | 8.4      | 14.92        |      |         |
| kHz   | COR      |       | AC/DC DIFFERENCE     |          |          |              | STD  | AVE T   |
|       | PPM      |       |                      |          |          |              | DEV  | COR PPM |
| 10.00 | 0        |       | ( 51 52              | 51       | 52)      |              | 0.5  | 51.5    |
| 10.00 | 0        |       | ( 35 34              | 29       | 33)      |              | 10.1 | 42.2    |
| 10.00 | 0        |       | ( 43 43              | 41       | 41)      |              | 8.1  | 42.1    |
| 10.00 | 0        |       | ( 39 43              | 44       | 43)      |              | 7.0  | 42.1    |
|       | 50.0     | 50.0  | FD 100.0             | 11.2     | 8.4      | 14.92        |      |         |
| kHz   | COR      |       | AC/DC DIFFERENCE     |          |          |              | STD  | AVE T   |
|       | PPM      |       |                      |          |          |              | DEV  | COR PPM |
| 5.00  | 0        |       | ( 19 21              | 19       | 18)      |              | 1.5  | 19.4    |
| 5.00  | 0        |       | ( 20 19              | 20       | 18)      |              | 1.1  | 19.3    |

NUMBER OF READINGS=H=.....64

NUMBER OF INDEP. TESTS=L=.....6

DEGREES OF FREEDOM=D1=.....58

POOLED ESTIMATE OF TEST STD.DEV. OF MEAN=S2  
 =S.D.T. (SEE S.P. 300,V.1, P. 316-40).....=1.02083

### 3. MEASUREMENT RESULTS AND UNCERTAINTIES

There are many factors which contribute to the uncertainty of ac/dc difference measurements of the type described in this report. Similar manual systems have been in operation for many years at NBS and their uncertainties have been documented [1-3]. DC reversal difference of a TE, self-heating and ambient temperature effects, drift effects due to non-equal time intervals during the voltage measurements, unbalanced lead impedances, and induced voltages from electromagnetic fields are some of the more common factors. The process of determining an estimated total uncertainty for a system is based upon experience with the system, careful measurements of standards with accurately known corrections, or intercomparison tests of two independent test methods [3]. The latter procedure, involving comparison of a well-characterized manual system with the new one, was followed, since the uncertainty sources are believed to be similar in both systems.

The system performance was verified by an extensive testing procedure which involved the use of a multi-range thermal voltage converter instrument as a transport standard. The transport standard was first tested for ac/dc differences at various combinations of applied voltages and frequencies using the MIDAS-based system. It was then tested, at similar voltages and frequencies with the same standard thermal voltage converters, using the manual testing technique which has been used for many years at NBS. A third test was performed, again using the MIDAS system. Finally, the MIDAS system was disassembled, physically relocated, reassembled, and tested for proper operation. Then the transport standard was tested a fourth time, again using the MIDAS system. It should be noted that not all voltage range-frequency combinations were tested for all four tests. However, in those cases where fewer than four tests were performed, the results indicated sufficiently small differences between at least two independent test methods to establish that further testing was not warranted. The results of these independent intercomparison tests are listed in table 6, and the range of ac/dc differences is listed in table 7. In evaluating these results, it must be remembered that, for calibrating multirange instruments like the transport standard, the manual test system has uncertainties of the same magnitude as the semiautomatic system. Hence, combined total uncertainties of the order of 100 and 200 ppm are possible depending upon the test frequency.

In table 7, the column listing "Voltage Range" refers to the input voltage range of the transport standard, the "Test Voltage" is the actual test voltage applied, and the different columns for frequency are the actual test frequencies used. The numbers listed under the frequency columns are the maximum differences (in ppm) of the calibrated ac/dc difference corrections for the transport standard as determined for at least two, and up to a maximum of four, of the test conditions described above. That is, the numbers reported are the range (magnitude of the maximum minus the minimum) of the ac/dc difference corrections measured for each test voltage and frequency. The total elapsed time between the first and final tests of the transport standard was about eight weeks.

Table 6. Transport standard ac/dc differences (ppm)

| Range      | Applied voltage volts | 20 Hz |       |       |       | 20 kHz |       |       |       | 50 kHz |        |       |        | 100 kHz |        |       |        |
|------------|-----------------------|-------|-------|-------|-------|--------|-------|-------|-------|--------|--------|-------|--------|---------|--------|-------|--------|
|            |                       | No. 1 | No. 2 | No. 3 | No. 4 | No. 1  | No. 2 | No. 3 | No. 4 | No. 1  | No. 2  | No. 3 | No. 4  | No. 1   | No. 2  | No. 3 | No. 4  |
| .25 - 0.5  | 0.5                   | --    | --    | --    | 49.2  | 58.4   | 67.0  | 57.4  | 49.2  | 106.3  | 112.0  | 102.9 | 93.4   | 144.3   | 137.0  | 132.5 | 120.9  |
| 0.5 - 1    | 1                     | --    | --    | --    | --    | 36.9   | 45.0  | 36.4  | --    | 71.8   | 74.0   | 71.9  | --     | 101.6   | 98.0   | 101.1 | --     |
| 1 - 2      | 2                     | --    | --    | --    | --    | 12.2   | 11.0  | --    | --    | 17.5   | 24.0   | --    | --     | 25.4    | 16.0   | --    | --     |
| 2 - 4      | 3                     | --    | --    | --    | --    | 7.8    | 6.0   | --    | --    | 13.6   | 14.0   | --    | --     | 15.2    | 15.0   | --    | --     |
| 4 - 8      | 8                     | --    | --    | --    | --    | 7.0    | 7.0   | --    | --    | 4.6    | 4.0    | --    | --     | 4.6     | 8.0    | --    | --     |
| 8 - 16     | 16                    | 21.8  | 7.0   | --    | --    | 9.0    | 1.0   | 1.6   | --    | 14.0   | -1.0   | 5.2   | --     | 6.1     | 0      | 2.8   | --     |
| 16 - 32    | 30                    | --    | --    | --    | --    | 5.9    | 3.0   | 10.7  | --    | 12.5   | 3.0    | 2.9   | --     | -2.9    | -12.0  | -3.9  | --     |
| 32 - 64    | 50                    | --    | --    | --    | 5.6   | 2.8    | 4.0   | --    | 5.6   | 3.0    | 4.0    | --    | 6.1    | -3.6    | -6.0   | --    | 6.1    |
| 64 - 125   | 98                    | --    | --    | --    | 19.1  | 18.1   | 20.0  | --    | 19.1  | 32.5   | 38.0   | --    | 37.6   | 103.8   | 116.0  | --    | 112.5  |
| 125 - 250  | 200                   | --    | --    | --    | 4.8   | 8.5    | 8.0   | --    | 4.8   | 0.4    | 1.0    | --    | -0.6   | -43.7   | -58.0  | --    | -43.5  |
| 250 - 500  | 500                   | --    | --    | --    | 3.1   | 6.8    | 5.0   | --    | 3.1   | -387.6 | -443.0 | --    | -386.7 | -754.0  | -788.0 | --    | -748.7 |
| 500 - 1000 | 500                   | --    | --    | --    | 43.0  | 20.5   | 29.0  | --    | 43.0  | 184.7  | 235.0  | --    | 239.2  | 1080.2  | 1227.0 | --    | --     |
| 500 - 1000 | 1000                  | --    | --    | --    | -25.8 | --     | -9.0  | --    | -25.8 | --     | 97.0   | --    | 26.6   | --      | --     | --    | --     |

No. 1 - Automatic System

No. 2 - Old Manual System #2, Rm. A144

No. 3 - Repeat Automatic System

No. 4 - Automatic System, Rm. A144

Table 7. Range of ac/dc differences for transport standard (ppm)

| <u>Voltage range</u> | <u>Test voltage (volts)</u> | <u>Test Frequency (kHz)</u> |           |            |
|----------------------|-----------------------------|-----------------------------|-----------|------------|
|                      |                             | <u>20</u>                   | <u>50</u> | <u>100</u> |
| 0.25-0.5             | 0.5                         | 18                          | 19        | 23         |
| 0.5 - 1              | 1                           | 9                           | 2         | 4          |
| 1 - 2                | 2                           | 1                           | 6         | 9          |
| 2 - 4                | 3                           | 2                           | 0         | 0          |
| 4 - 8                | 8                           | 0                           | 1         | 3          |
| 8 - 16               | 16                          | 8                           | 15        | 3          |
| 16 - 32              | 30                          | 8                           | 10        | 9          |
| 32 - 64              | 50                          | 3                           | 3         | 10         |
| 64 - 125             | 98                          | 2                           | 6         | 12         |
| 125 - 250            | 200                         | 4                           | 2         | 14         |
| 250 - 500            | 500                         | 4                           | 50        | 39         |
| 500 - 1000           | 500                         | 22                          | 54        | 147        |
| 500 - 1000           | 1000                        | 17                          | 70        | --         |

The test results show that at 20 kHz the average value of the range of ac/dc differences for all voltages is only 8 ppm. At 50 kHz the average value of the range is 19 ppm, and at 100 kHz, where skin effects and stray capacitance effects predominate, the largest range (at 500 V) was 147 ppm. However, this large range is within the expected combined total uncertainty of 200 ppm for the two systems. Even with this one range greater than 100 ppm, the average value of the range at 100 kHz is still only 23 ppm. No intercomparison results were obtained at 1000 V, 100 kHz, since the high-voltage-amplifiers in both systems could not supply sufficient power at that voltage-frequency combination.

Additional intercomparison tests were made using a single-range, coaxial type thermal voltage converter with large, but accurately known, ac/dc differences. The summary of the test results is shown in table 8. From the data, it is obvious that the two systems agreed well within the estimated total uncertainty limits. In fact, the data clearly show that the MIDAS-based system performed much better than had been anticipated when the project was undertaken.

As a final check of the system's performance, intercomparison tests were made using a single-range, coaxial type converter, which is used as a working standard for ac/dc testing at NBS. The results of these tests are summarized in table 9. Again, the results indicate excellent agreement between the two systems.

#### 4. CONCLUSIONS AND RECOMMENDATIONS

The results of the work reported indicate that it is possible to measure ac/dc differences semiautomatically with uncertainties about the same as those obtained with manual testing techniques. The major advantage of the system appears to be the elimination of most of the tedium involved in manual testing, in which deflections of light beam galvanometers must be observed and recorded.

For future work, it appears that further improvements in system operation can be obtained by development of self-balancing TE comparators. Additionally, by taking advantage of improvements in digital voltmeter sensitivity, stability, linearity, and resolution, desktop computers, and system components whose operation is compatible with new digital/analog interfaces, it may be possible to develop improved ac/dc difference testing techniques.

#### 5. ACKNOWLEDGEMENTS

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Table 8. AC/DC difference for TVC "FA 50" (ppm)

| 1<br>Applied<br>voltage | 2<br>Frequency<br>kHz | System      |            | 3-4<br>Difference |
|-------------------------|-----------------------|-------------|------------|-------------------|
|                         |                       | 3<br>Manual | 4<br>MIDAS |                   |
| 50                      | 5                     | 24          | 22         | 2                 |
| 50                      | 10                    | 52          | 50         | 2                 |
| 50                      | 20                    | 116         | 113        | 3                 |
| 50                      | 50                    | 308         | 305        | 3                 |

Table 9. AC/DC difference for TVC "FC 100" (ppm)

| 1<br>Applied<br>voltage | 2<br>Frequency<br>kHz | System      |            | 3-4<br>Difference |
|-------------------------|-----------------------|-------------|------------|-------------------|
|                         |                       | 3<br>Manual | 4<br>MIDAS |                   |
| 100                     | 20                    | 3           | 5          | -2                |
| 100                     | 50                    | 3           | 4          | -1                |
| 100                     | 100                   | 13          | 18         | -5                |

## 6. REFERENCES

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## APPENDIX A

### Hardware

Equipment lists, parts lists, and wiring diagrams of the equipment used in the NBS Semiautomatic AC/DC Thermal Voltage Converter Calibration System are contained in this appendix.

The use of trade names or company products does not constitute endorsement or recommendation by the National Bureau of Standards, and does not imply that the products named are necessarily the best available for the purpose.

#### 1. List of Equipment.

1. Data Precision Model 5740 Frequency Meter.
2. Fluke Model 3330B Programmable DC Voltage Standard.
3. Hewlett-Packard Model 745A AC Voltage Standard, option H18.<sup>1</sup>
4. Hewlett-Packard 746A High Voltage Amplifier.
5. Leeds & Northrup Model 9829D Digital Linear Amplifier.
6. Guildline Model 9577 Digital Voltmeter with BCD interface.
7. Data Precision Model 175 Digital Multimeter (2 ea).

#### 2. Parts list for High Voltage Switching Module.

1. D1-D4: IN5620 diodes.
2. T1: Rectifier transformer. Universal Rectifier Corp., model RT201.
3. K1-K4: Relays. Magnecraft Electric Co., model W158HVX1, SPDT, DB-DM, 24 VDC. Rated 200 mA coil, 5 kV dc, 120  $\Omega$  coil.
4. S1, S2: CTS Rotary switch, series 212, #T205.
5. P1: Cable connector. Gen-Rad, type GR874-CA.
6. J1: Panel connector. Gen-Rad, type GR874-PBA.

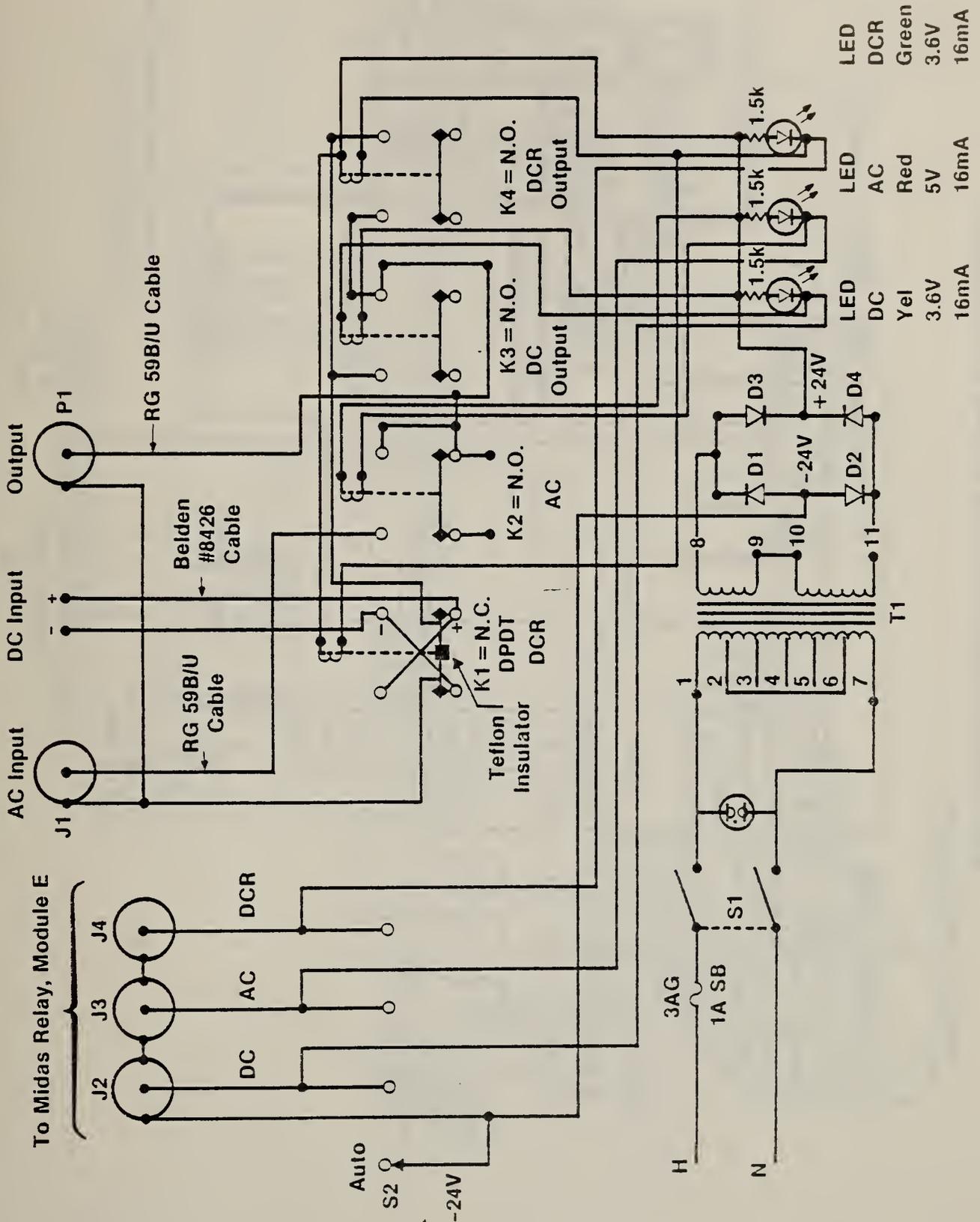
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<sup>1</sup>For the frequency output connector of the ac calibrator, a triax BNC to regular BNC adaptor is required. The adaptor used was made by Trompeter Electronics, part number AD-PL76-E1-B120.

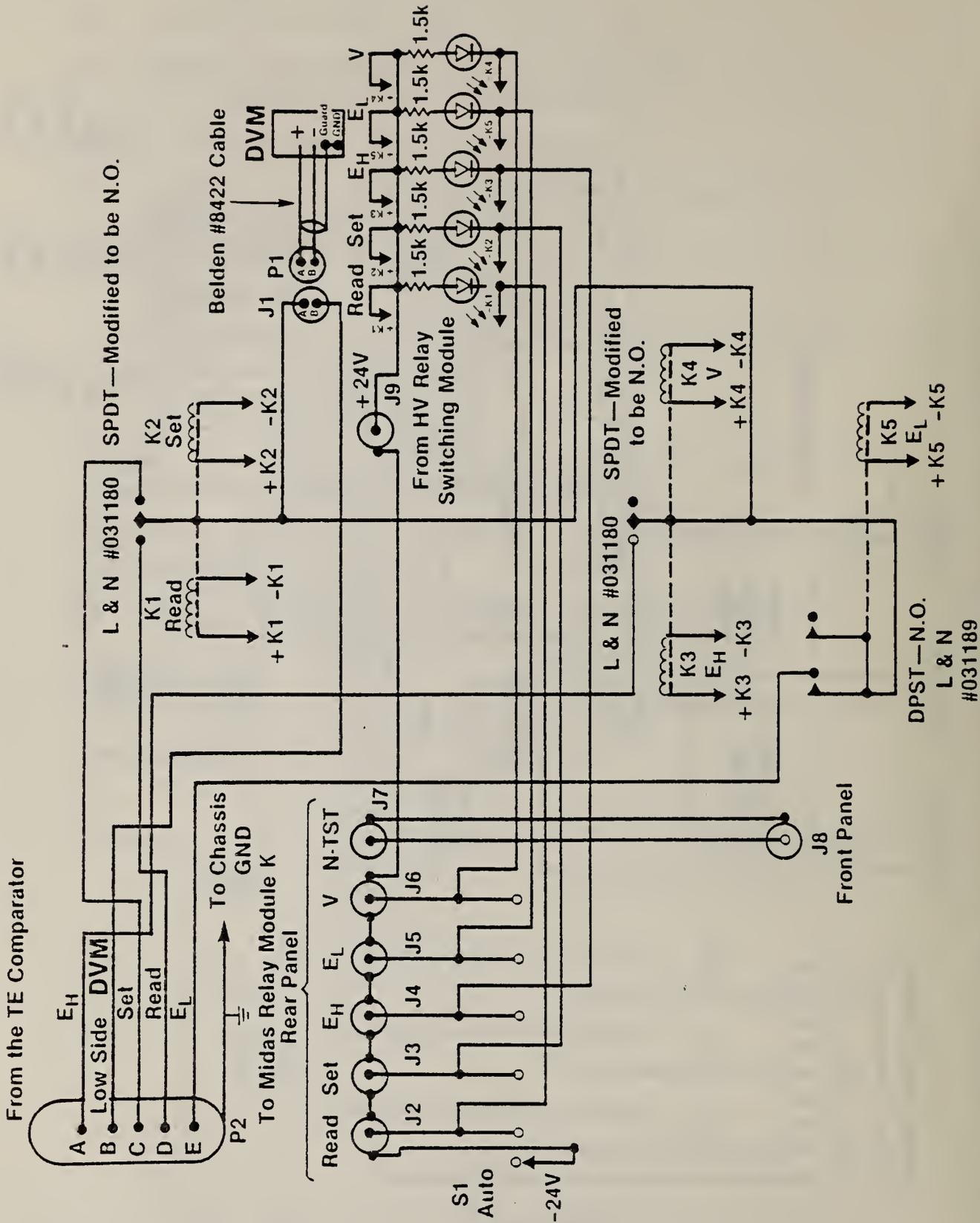
7. Pilot light. Industrial Devices, 215 0A1.
  8. J2-J4. BNC male panel mount connectors isolated from panel.
  9. All resistors 1/4 W.
3. Parts list for Low-Thermal-Noise Switching Module.
1. K1-K5: Solenoids. Guardian Electric Co., pull type #24DC. Coil voltage 24 V dc. 114  $\Omega$  coil resistance.
  2. J1: Panel jack. Amphenol #3102A receptacle, #10S-02P insert.
  3. P1: Cable plug. Amphenol #3106B connector, #10S-02P insert. #AN3057 cable clamp.
  4. J2-J9: BNC male panel mount connectors isolated from panel.
  5. P2: Cable plug. Amphenol #3106B plug, #14S-05 insert, #AN3057-6 cable clamp.
  6. S1: C.T.S. rotary switch, series 212, #T205.
  7. All L.E.D.'s red, 5V, 16 mA.
4. Parts list for TE Comparator.
- J1 & J2: Panel jack. Amphenol #3102A receptacle, #10S-02P insert.
- J3: Panel jack. Amphenol #3102A receptacle, #14S-05P insert.
- J4: Panel jack. Amphenol #3102A receptacle, #10SL-03P insert.
- Battery: Mallory Duracell RM42R 1.35 V.
- Meter: 0-1 mA, DC.
- R1, R2: 10  $\Omega$  Gen-Rad #602-302.
- R3: Beckman Helipot #SA 4391, 10 turn, 100  $\Omega$ ,  $\pm 3\%$ .  
(Lindeck potentiometer fine adjust).
- R4: 750  $\Omega$ , 10%, 1/2 W, carbon.
- R5: Beckman Helipot #SA4912, 10 turn, 100  $\Omega$ ,  $\pm 3\%$ .
- R6, R7: 100  $\Omega$ ,  $\pm 10\%$ , 1/2 W carbon.
- R8, R9: 53k  $\Omega$ ,  $\pm 10\%$ , 1/4 W, carbon.
- R10, R11: 1  $\Omega$ ,  $\pm 1/2\%$ , 1 W, precision pie wound.

- R12: Precision pie wound,  $1k \Omega$ ,  $\pm 1/2\%$ , 1 W.
- R13: Precision pie wound,  $0.05 \Omega$ ,  $\pm 1/2\%$ , 1 W.
- R14: Beckman Helipot #SA5427, 10 turn,  $100 \Omega$ ,  $\pm 3\%$ .  
(Kelvin-Varley divider fine adjustment).
- R15: Gen-Rad #602-303,  $100 \Omega$ .
- S1: Leeds & Northrup 12 position, 2 pole rotary selector switch #031262. (Function switch).
- S2: Leeds & Northrup 12 position, 3 pole rotary selector switch #031263.  
(Kelvin-Varley divider coarse adjust).
- S3: Leeds & Northrup 12 position, 6 pole rotary selector switch #031266.  
(E-high or E-low selector switch).
- S4: SPST bat handle toggle switch.
- S5, S6: Set and read detector sensitivity switches. Leeds & Northrup  
SPST #031187.
- S7, S8: Set and read switches. Leeds & Northrup Guarded Low Thermal Key  
switch DPST #031189.
- S9: C.T.S. 7 position 2 pole rotary switch, series 212, #T205.  
(Lindeck potentiometer coarse adjust).

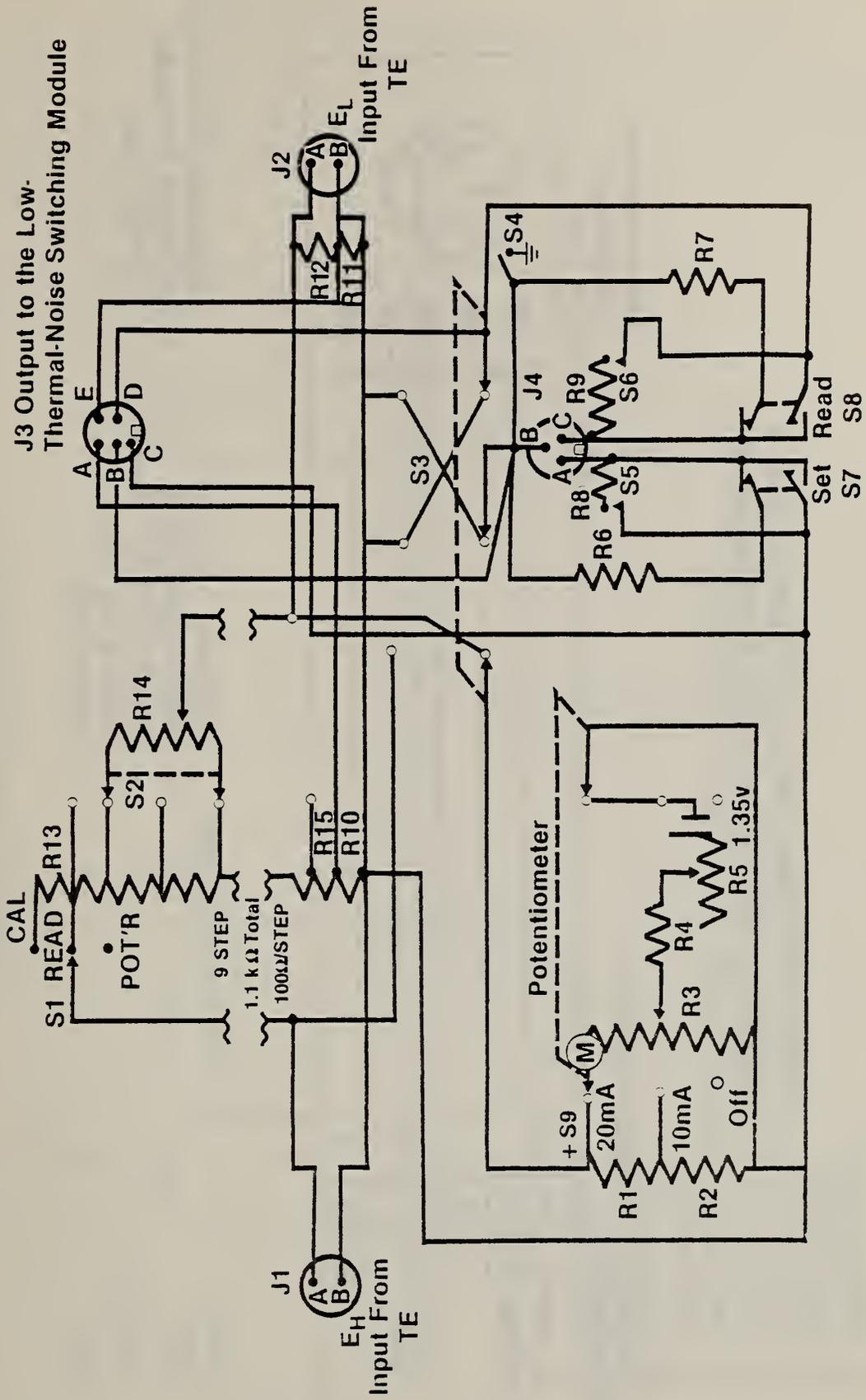
# High Voltage Switching Module Wire Diagram



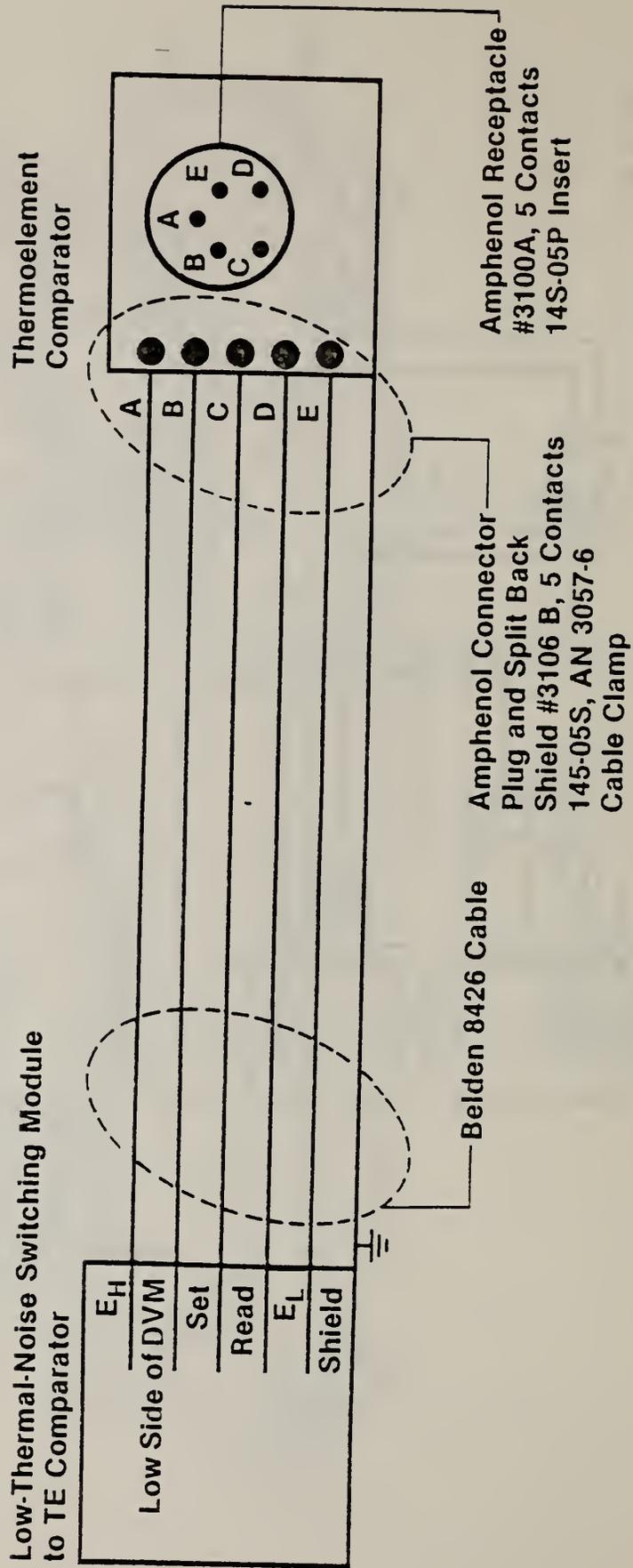
# Low-Thermal-Noise Switching Module Wire Diagram



# NBS Model "BB" TE Comparator



# Cable Between the Low-Thermal-Noise Switching Module and the TE Comparator



# Midas Equipment List

| Slot #             | 11      | 17      | 18      | 19              | 20      | 21       | 22       | 23      | 24                |
|--------------------|---------|---------|---------|-----------------|---------|----------|----------|---------|-------------------|
| Midas Add.         | K       | H       | G       | F               | E       | D        | C        | B       | A                 |
| Midas Power Supply | Relay   | BCD I/O | BCD I/O | BCD Multiplexer | Relay   | BCD Reg. | BCD Reg. | BCD I/O | System Controller |
| Model              | M70-040 | M70-190 | M70-190 | M70-030         | M70-040 | M70-140  | M70-140  | M70-190 | M70-010B          |
|                    | Vacant  |         |         |                 |         |          |          |         |                   |

- Slot #
- 10 Midas Power Supply
  - 11 Relay, Low-Thermal-Noise Switch, V = 1, EL = 2, EH = 3 Set = 4, Read = 5, NTSTF = 6 From Top Down
  - 17 BCD I/O, Guildline
  - 18 BCD I/O, Dana
  - 19 BCD Multiplexer
  - 20 Relay, High Voltage Switch, DCR = 1, AC = 2, DC = 3 From Top Down
  - 21 BCD Reg., Fluke DC Voltage
  - 22 BCD Reg., H.P. AC Voltage
  - 23 BCD I/O, DVM
  - 24 System Controller

## APPENDIX B

### ACDCHV Detailed Program Description and Program Listing

For ease of understanding the following detailed narrative program description, the reader may find it useful to refer to the list of program variables on page 40, and the program listing on page 44. Although not included in this report, a detailed program flow chart is available upon request.

The program begins by describing the software and appropriate reentry points, as well as system limitations which would result in over-voltages. Lines 20-108 are print statements which display the descriptive information and warnings on the CRT. Statement 109, in which the program shunts around a variable index (lines 110-1020) and a data header (lines 1030-1170), is inserted when debugging, and deleted for formal testing when a heading is desired on the printed data sheet. In statements 1180-1280, string and array variables are dimensioned, and simple variables are initialized. The statements in lines 1290-1310 generate, through a read command and a series of data statements (lines 1320-1400), a library containing corrections to those TE standards that might be used during an ac/dc difference test.

The constants stored in data lines 1320-1390 are those which are used to calculate the value of the standard TE's dimensionless characteristic "n." Since n varies with applied voltage, its value can be related to the TE's measured emf output, E (in mV). The value of n is assumed to vary linearly with E. Thus, for example, for the standard "F1" in line 1320, n is calculated as

$$n = 1.98 - 0.039E.$$

String variables used for instructions to MIDAS are then dimensioned and defined (lines 1400-1420). Since instructions from, and data sent to, MIDAS are done in real time, delay statements are used to handle timing intervals between reception of programmed instructions and acquisition of data. An upper limit for these delay statements is defined in statement 1430 concluding the system's software initialization.

A series of linked subroutines comprise the body of the program which actually begins at line 1440. A print command causes the CRT to beep, prompting the operator to enter, via the CRT keyboard, a test voltage, test range, and standard TE range after a request for such test requirements has been displayed (line 1450). A conditional statement in line 1470 tests the status of flag S. S is set to 1 after an initial test so that for any succeeding tests, the program jumps to subroutines which turn off both dc and ac voltages, restoring each set of test parameters when required (lines 5970-6050 for dc, and 6060-6160 for ac). During a first run, however, S equals zero so the program falls through, first to set the dc voltage, then to set the ac.

Both voltage-setting routines follow similar general formats. Statements in lines 3430-3990 set the ac voltage, while statements 4640-5190 set the dc. Before requesting voltage, range, and frequency (ac only) parameters, instructions for coding these parameters are displayed on the CRT. Any variables which may yet be necessary are then established. These include temporary variables (such as F18, R18, and V28 in ac, and R2 and V18 in dc), all of which are used to store parameters when turning supplies on and off during high voltage tests. Any flags for branching around certain instructions when testing at high voltages are also included here; for example, D in the ac routine (lines 3620-3650). Because the initial instructions to MIDAS differ, depending on a preselected range, conditional statements determine program flow to one of several sets of separate commands. Each of these command sets issues an initial instruction to MIDAS for a particular range before going back to the voltage set subroutine for more generalized instructions which send, through MIDAS, previously defined parameters. After MIDAS has sent the commands to those instruments being programmed, the operator is prompted, via the CRT, to check if each device has actually responded correctly. Should the operator indicate that a response is incorrect, the program recycles the subroutine to receive new instructions. If operator response indicates that the instruments have responded correctly, control is returned to statement 1520 of the main program.

After both dc (1500) and ac (1510) voltages have been set, instructions are displayed telling the operator to select the E-high comparator input, turn off the Lindeck potentiometer and the ground switch of the comparator and set the voltmeter to its 10 mV range. A variable for the test number is incremented, while both "dc" and a low-thermal-noise (K2) relay are closed. The operation of the high voltage relays, as well as those solenoids contained in the low-thermal-noise switch module, is accomplished by instructions contained in repeatedly-accessed subroutines in lines 5690-5900. Next, the dc power supply is turned on to the previously programmed voltage value (1610). Before the voltmeter is read (1640), the program executes a time delay (1620-1630) to permit the TE to reach thermal equilibrium. Statements 1641-1651 ask which standard TE is being used and check through a data library for its correction. This correction is used in each of two formulas, only one of which is accessed, contingent upon whether the standard or the UUT is connected to the E-high or E-low input of the comparator (1750-1770).

When  $E_s > E_t$  the program variable K is computed as

$$K = E_t n_s = E_t (M_s - N_s E_s),$$

and, when  $E_t > E_s$ , K is computed as

$$K = E_s n_s = E_s (M_s - N_s E_s),$$

where the subscripts t or s refer to the UUT or the standard TE, respectively, and M and N are constants as defined in the program

variable list on page 40. These equations have been derived in [2]. The emf of the TE connected to the E-high input is read first by the voltmeter, and its value displayed on the CRT. Should E-low have a greater emf output than the TE connected to the comparator's E-high input, the operator is instructed to switch comparator connections, the test is aborted (1655-1718), and the initialization process begun again. If the standard and test TE's are properly connected to the comparator, K is computed and printed on the data sheet along with voltage, test range, standard TE range, and emf outputs for both the standard and the UUT.

If the UUT's emf actually is E-high, the operator is prompted to select the E-high input of the TE comparator (if E-test < E-high, the input selector switch remains at the E-low position). The potentiometer is turned on, the 10  $\mu$ V range of the voltmeter selected, and the potentiometer adjusted until the voltmeter indicates within  $\pm 500$  nV. Instructions and prompts in the statements in lines 1830-1950 cue the operator to execute these manual operations. Then relay K2 opens and relay K1 closes (lines 1970-1990). The operator is then instructed to adjust the Kelvin-Varley voltage divider ( $\pm 100$  nV), after which dc voltage parameters are stored, and the dc standard turned off. Both "dc" and K1 relays open now, while relay K2 closes. Column headings for the data sheet are printed, and variables for statistical calculation are initialized.

Appropriate frequency corrections are computed for the standard TE. Statements 2220-2230 prompt the operator to define the test frequency, and statements 2240-2320 use this frequency value to determine the correction and truncate the computed correction to a whole number. Now the "dc" relay closes, and the dc power supply is turned on to the previously selected test voltage, at which point the K2 relay closes. The operator is then directed to readjust the potentiometer, after which the dc voltage and range values are stored, the power supply turned off, and the "dc" relay opened. Then the "ac" relay closes and the ac power supply is turned on, first at 105 volts and finally to the proper high voltage. A time delay in lines 2480-2490 allows the ac supply to settle and the TE to reach thermal equilibrium before transferring control to an ac voltage check subroutine (4000-4630) that adjusts the ac voltage so that the output of the test TE is within 1000 nanovolts of its output with dc voltage applied. The subroutine branches, depending upon whether the ac voltage is too high or too low. The ac voltage is adjusted to provide nominally equal UUT output only with direct dc voltage applied, and not when reversed dc is applied. Furthermore, this ac voltage adjustment is made only once at the beginning of the measurement sequence to obtain four determinations of ac/dc difference. Hence, it is possible, for UUT's with large dc reversal differences, for second-order errors to become significant. However, the multirange instrument and single range thermal converters tested with this system did not possess large dc reversal differences.

The system was intended to calibrate high-quality thermal converters. Hence, additional balancing steps to eliminate uncertainties due to large dc reversal difference (i.e., difference between the dc direct and

reverse voltages required for the same TE emf output of the UUT) were not needed. For the worst case, using 2.0 and 1.6 as the two extremes of the characteristic  $n$  which may occur for the standard and UUT TE's, it can be shown [4] that systematic uncertainties of less than one-fourth the UUT's dc reversal difference will occur. Minor software changes can eliminate this systematic error if large reversal voltages are anticipated. The changes would amount to adjusting the ac voltage for a TE output equal to that when dc reversed voltage is applied to the test circuit. The only penalty for such a change in the operating procedure would be an increase in testing time of perhaps one or two minutes (for four determinations of ac/dc difference).

There is also the possibility of a systematic uncertainty if the ac or dc voltage standards drift during a sequence of four determinations. However, for the same extremes of  $n$ , the uncertainty is only 10 ppm if either source drifts by as much as 100 ppm. The STABLV and STABHV programs readily provide information about the stabilities of the sources.

Once the ac voltage has been adjusted for about equal TE output as when dc is applied, relay K2 opens and relay K1 closes (2510-2540). Cautions are displayed on the CRT to allow the voltmeter to stop drifting before rebalancing the divider, should that be necessary. Statements in lines 2600-2610 generate a time delay before the program jumps to test the 10 voltmeter readings (5500-5650) to determine if the standard deviation of an observation of 10 readings is  $< 200$  nV. The test routine allows for up to five reading sequences to be obtained before the test is aborted and a suitable warning displayed on the CRT.

AC/DC difference is reported on the basis of the average of four determinations. Each determination is calculated from the voltage measurements with ac, dc+, dc-, and ac voltages applied simultaneously in this sequence to the standard and test TE's. The last ac reading of one determination becomes the first ac reading of the next determination. Each reading is taken by closing the appropriate relays, bringing up the power supplies to previously programmed values, displaying the reading in nanovolts, then storing the voltage parameters, powering down, and opening the relays. This measurement process is accomplished by means of statements in lines 2650-3050 and concludes the midsection of the program.

The final section of the program computes statistical parameters, formats the final output, generates a copy of the test data, and provides measurement options to the operator. Statements 3060-3130 calculate the mean of the four determinations and the standard deviation of an observation in ppm, while statements 3140-3150 format the printed data, and the statement in line 3160 causes the data to be printed. Should the operator wish to run another test, variables used to determine a pooled standard deviation are then incremented in lines 3170-3230. Finally, options are displayed (3240-3250) asking whether to repeat a test with or without averaging, to change parameters, or to terminate. Since ac was the last measurement to be taken, its voltage is turned off, although the ac

parameters are automatically stored for potential reruns (3275). Statements 3280-3350 transfer program control to the operator-selected option. If the operator has chosen to repeat a test without averaging, lines 3380-3410 delete the pooled standard deviation data.

The standard deviation of an observation printed on the data sheet is calculated for the four determinations of ac/dc difference at a fixed voltage and frequency from the following:

(Standard deviation)<sup>2</sup> = (Variance), and the

$$\text{Variance} = \frac{\sum_{i=1}^{n_k} (x_i - \bar{x})^2}{n_k - 1},$$

where,  $\bar{x} = \frac{\sum_{i=1}^{n_k} x_i}{n_k}$ , and  $n_k$  is the number of determinations at a fixed

voltage and frequency; i.e., the number of readings in test  $k = n_k$ .

The final statistics which are printed on the data sheet are calculated using the variables

H = total number of readings,

L = Number of independent tests,

Df = Degrees of freedom = H-L,

S2 = Pooled estimate of the test standard deviation of the mean  $\equiv$  standard deviation of the test (SDT).

An estimate of the total random uncertainty is calculated as three times the SDT and this product is therefore an estimate of the average  $3\sigma$  value for the test, and is calculated as

$$3\sigma = 3 \left\{ \frac{\sum_{k=1}^t \left[ \sum_{i=1}^{n_k} (X_i - \bar{X})^2 \right]}{(n-t) (n/t)} \right\}^{1/2},$$

where, the degrees of freedom =  $n-t$ ,

total number of readings =  $n = \sum_{k=1}^t n_k$ ,

number of independent tests =  $t$ .

These concepts are discussed fully in [9], pp. 316, ff.

## ACDCHV PROGRAM VARIABLES

Note:  $\emptyset$  = zero and not letter "oh"

| <u>Variable Name</u> | <u>Definition</u>  |
|----------------------|--|
| A                    | Voltage applied to test and standard TE.   |
| A $\emptyset$        | Array used to store the four determinations of ac/dc difference.   |
| A2                   | Variable in the subroutine used to increase or decrease the ac voltage when driving the UUT's output to within 1000 nV of its value with dc voltage applied. |
| A4                   | Variable which is input by the operator after verifying the dc voltage ( $\emptyset$ or 1).  |
| A5                   | Variable which is input by the operator after verifying the ac voltage and frequency ( $\emptyset$ or 1).  |
| A6                   | Variable which is input by the operator after determining whether or not to change the frequency after the ac voltage is set.                                |
| B                    | Voltage range of test TE.  |
| B $\emptyset$        | Average of all determinations at one voltage and frequency.  |
| B1                   | Average of the four latest determinations of the test. B1 is used in the computation of the standard deviation of the test.                                  |
| B\$                  | Array used to store the data related to a particular TE.   |
| C                    | Frequency correction to standard TE which is calculated by using test frequency (P).   |
| C7                   | Variable used to increment or decrement the ac voltage to drive the UUT's output to within 1000 nV of its value with direct dc applied.                      |
| C\$                  | String containing name of standard TE.   |
| C $\emptyset$ \$     | Variable used in input string to dc source to set range, polarity, remote trip, and voltage trip range.  |
| D                    | Flag to initially turn on ac supply at 105 V, and then return and set the correct voltage and range.   |
| D1                   | Variable used for degrees of freedom in statistical calculations. D1 = H-L.  |
| D\$                  | String used to input date.   |

| <u>Variable Name</u> | <u>Definition</u>   |
|----------------------|---|
| E                    | E-high voltage reading, in mV.  |
| E9                   | E-low voltage reading, in mV.   |
| E1-E4                | DLA voltage difference readings with ac, +dc, -dc, and ac voltages applied to the standard and UUT TE's.  |
| F0\$                 | Used to input frequency to the ac source.   |
| F1\$                 | Storage variable for the ac source frequency used in the ac voltage setting routine.  |
| G                    | Dummy variable.   |
| H                    | Total number of determinations of ac/dc difference per test run.  |
| I                    | Variable defining a for/next loop in which the standard TE code file is established.  |
| I0                   | Variable used to designate the first element in array A (the test voltage) when defining the variables M and N. Also used to define E1 = near-null voltage reading with ac applied, E2 = reading with +dc, E3 = reading with -dc, E4 = reading with ac. |
| I\$                  | String used to input the test instrument manufacturer, name, and model number.  |
| I8                   | Variable used to define the for/next time interval loop.  |
| I9                   | Variable used to define the for/next "wait" timing loop; e.g., to allow the dc or ac supplies to settle, or to allow time for a TE to reach thermal equilibrium.  |
| J                    | Flag for abort and total reset.   |
| J1                   | Variable used to define for/next loop in which X6 is computed. J1 is used in the pooled estimate of the test standard deviation of the mean.  |
| K                    | Result of the standard TE's emf multiplied by the TE characteristic $n_s$ when $E_s < E_t$ , or the test TE's emf times $n_s$ when $E_s > E_t$ .  |
| K0                   | Variable used to define a for/next loop in which the ten DLA near-null voltage readings are obtained, and then calculate the standard deviation of the ten readings.  |

| <u>Variable Name</u> | <u>Definition</u>  |
|----------------------|--|
| L                    | Number of independent tests for a complete test run; i.e., for all voltages and frequencies.                           |
| M                    | One of two constants used in the calculation of $n_s$ . The other constant is N.                                       |
| MØ                   | Variable used to implement MIDAS calls. MØ is the computer's PASLA channel number in decimal.                          |
| R1                   | Variable used to set the range of the dc supply.   |
| R2\$                 | Variable used to store the range of the dc supply before turning it off.   |
| RØ\$                 | Variable used to select the range for the ac supply.   |
| R\$                  | Character string reference used for relay operation.   |
| R1\$                 | Variable used to store the range of the ac supply before turning it off.   |
| S                    | Flag for initial dc and ac voltage ranges.   |
| S1                   | Standard deviation of an observation for four or more determinations of ac/dc difference at one voltage and frequency. |
| S2                   | Pooled estimate of the test standard deviation of the mean.  |
| T                    | Decision point variable.   |
| TØ                   | Time delay variable.   |
| T\$                  | Output format string.  |
| V\$                  | MIDAS input string.  |
| VO\$                 | String used to set voltages on both ac and dc supplies.  |
| V1\$                 | Variable used to store the dc voltage value in the dc voltage setting routine.   |
| V2\$                 | Variable used to store the ac voltage value in the ac voltage setting routine.   |
| V                    | Numeric value of V\$. V is the value of the voltage reading.   |

| <u>Variable Name</u> | <u>Definition</u>  |
|----------------------|--|
| W                    | Divisor used in the calculation of the mean of four or more determinations at one voltage and frequency. |
| X,X1,X2              | All used in the standard deviation of the test (SDT) calculation.  |
| X5,X6,X7             | Used in calculating the pooled estimate of the standard deviation of the mean.                           |
| Y                    | Intermediate variable used in calculating Y1.  |
| Y1                   | Standard deviation of ten voltmeter readings.  |
| Z                    | Counter in the five standard deviation abort subroutine.   |

## ACDCHV PROGRAM LISTING

```

20 ;"PROG. NAME=ACDCHV"
30 ;"PROG. TESTS AC-DC DIFF. AT HI V(>100V;RANGE=1000)"
40 ;" PROGRAM CONTAINS SUBROUTINE(S) FOR TURNING ON & OFF"
50 ;" HI.V. AMP.(AC) & FLUKE (DC,DCR) WHEN SWITCHING RELAYS."
60 ;" THIS PROGRAM HAS AUTOMATIC CONTINGENCY FOR TURNING ON HI.V.AMP."
70 ;" INITIALLY AT 105 VOLTS."
80 ;" PROG. CAN BE USED AT BOTH LO. & HI. VOLTAGES."
90 ;" TO RESET, RUN 5910."
95 ;" TO MAKE DECISION(S) AFTER INITIAL RUN, RUN 3240."
96 ;
97 ;
98 ;"          CAUTION"
100 ;"      READ THIS CAREFULLY!"
101 ;" FLUKE ALWAYS USES 1KV RANGE! HENCE, FOR LO VOLTAGE TESTS"
102 ;" TO PREVENT DC OVERVOLTAGE, USE PRECEEDING ZEROES FOR CORRECT V"
103 ;"EG. 9V ON 1KV RANGE=0090000, AND 90V ON 1KV RANGE=0900000"
104 ;"MAKE SURE HP HI-VOLT. AMP. IS ON"
105 ;"TIME DELAY TO SET IN LINE 1430"
106 ;
107 ;
108 ;
109 GOTO 1180
110 REM  INDEX
111 REM  THIS PROG. USES THE FOLLOWING VARIABLES
112 REM  A,A0,A2,A4,A5,B,B0,B1,B5,C,C7,CS,C0S,
113 REM  D,D1,DS,E,E1,E2,E3,E4,E9,F0S,F1S,G,H,
114 REM  I,I0,I8,I9,I5,J,J1,K,K0,L,M,M0,M1,M2,
115 REM  N,NS,O,OS,O2S,P,P0,R,R0,R1,R2,RS,R0S,RIS,
116 REM  S,S1,S2,T,T0,TS,V,VS,V0S,V1S,V2S,W,
117 REM  X,X1,X2,X5,X6,X7,Y,Y1,Z
120 REM  PRG. LINES 110-1020: PROGRAM INDEX & DEF. OF VARIABLES
130 REM  1030-1170: TEST DATA HEADING PRINTOUT
140 REM  1180-1460: INITIALIZATION OF DATA
145 REM  1470: CONDITIONAL FOR RANGE CHANGE
150 REM  1480: CALL TO DC VOLTAGE SET SUB.
160 REM  1490: CALL TO AC VOLTAGE SET SUB.
170 REM  1530-2320: EH & EL READINGS & VARIABLE INPUTS
180 REM  2330-2570: AC VOLTAGE APPLIED
190 REM  2590-3050: AC-DC-DCR READINGS
195 REM  2940-2950: SAFETY MEAS. - CLOSE READ IN CASE OPEN
200 REM  3060-3230: DATA PRINT & STATIS. CALCS.
210 REM  3240-3410: END OF TEST DECISION POINT
220 REM  3420-3990: AC VOLTAGE SET ROUTINE
224 REM  3600: INITIAL STORAGE OF AC FREQUENCY
226 REM  3730-3740: INITIAL STORAGE OF AC PARAMETERS
230 REM  4000-4630: AC CHECK ROUTINE (DRIVES AC WITHIN
240 REM  100 NANOVOLTS OF DC)

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241 REM NOTE: TO CHANGE NULL RANGE - LINE 4080
242 REM TO CHANGE INCREMENT - LINES 4150 & 4400 FOR L.V.
243 REM FOR H.V. INCREMENT - LINES 4170 & 4420
250 REM 4640-5190: DC VOLTAGE SET ROUTINE
255 REM 4760-4770: INITIAL STORAGE OF DC PARAMETERS
260 REM 5200-5390: STATIS. PRINT ROUTINE FOR POOLED S.D.
270 REM 5400-5490: DLA READ ROUTINE
280 REM 5500-5680: STD. DEV. TEST (OF DLA READINGS)
290 REM 5690-5790: E-MOD. RELAY SET ROUTINE (HI. V. SW.)
300 REM 5800-5900: K-MOD. RELAY SET ROUTINE (LO. THER. SW.)
310 REM 5910-6640: RESET, TURN-OFF & TURN-ON SUBROUTINE
312 REM 5950-6050: TURN-OFF FLUKE & REDEFINE DC PARAM.
314 REM 6060-6160: TURN-OFF HI.V.AMP. & REDEFINE AC PARAM.
316 REM 6170-6330: TURN-ON FLUKE & RESTORE DC PARAM.
318 REM 6340-6630: TURN-ON HI.V.AMP. & RESTORE DC PARAM.
320 REM RUN 3360: TO CHANGE RANGE
330 REM 1510: TO CHANGE FREQUENCY
340 REM 2330: TO REPEAT TEST
350 REM 3290: TO RESET RELAYS ONLY
360 REM 3380: TO TO REPEAT W/O AVE.
370 REM 5200: TO GET POOLED S.D. STATIS. PRINTOUT
380 REM 5910: TO ABORT & RESET ALL RELAYS
390 REM A=VOLTAGE APPLIED TO STANDARD TE.
400 REM A0=ARRAY USED TO STORE THE 4 DETERMINATIONS.
410 REM A2=INCREMENTED IN AC VOLTAGE CHECK ROUTINE
420 REM B=RANGE OF TEST TE
430 REM B0=AVE. OF ALL RDGS. OF A PARTICULAR TEST.
440 REM B1=AVE. OF ONLY 4 LATEST READINGS.
450 REM B3=ARRAY USED TO STORE EACH TE'S CONSTANTS.
460 REM C=STD. TE FREQ. CORR. DETERMINED FROM INPUT FREQ=P
470 REM C7=VOLTAGE INCREMENT IN AC BALANCE ROUT.
480 REM C8=STRING CONTAINING I.D. OF STD. TE
490 REM C08=USED IN INPUT STRING TO DC SOURCE
500 REM D=COUNTER FOR INITIAL INPUT (105 V) FOR HI.V.AMP.(AC)
510 REM D1=DEGREES OF FREEDOM=H-L
520 REM D8=STRING USED TO INPUT DATE
530 REM E=E-HIGH MILLIVOLT READING (EH)
540 REM E9=E-LOW MILLIVOLT READING (EL)
550 REM E1 TO E4=ALTERNATING AC-DC-DCR-AC NULL READINGS
560 REM F08=USED TO INPUT FREQ. TO AC SOURCE
570 REM G=DUMMY VARIABLE
580 REM H=TOTAL NO. OF DETERMINATIONS PER RUN
590 REM I8=STRING USED TO INPUT TEST INSTRUMENT MFG. & MODEL NO.
600 REM J=COUNTER FOR ABORT & TOTAL RESET
610 REM K=PRODUCT RESULT OF STD. EMF*STD.
612 REM TE CHARACTERISTIC (N, LOWER CASE)
614 REM WHEN ES<ET
616 REM OR TEST EMF*STD TE CHARACTERISTIC
618 REM (N, LOWER CASE) WHEN ES>ET
620 REM L=TOTAL NO. OF TESTS PER RUN
630 REM M=CONSTANT USED TO DETERMINE STD. TE
631 REM CHARACTERISTIC N-SUBSCRIPT S (N, LOWER CASE)
640 REM M0=IN MIDAS CALL IS THE PASLA CHANNEL NO. IN DEC.
650 REM M1=MAX. LENGTH OR TERMINATING CHAR.
651 REM OF MIDAS INPUT STRING
660 REM M2=STATUS VARIABLE SET AFTER
661 REM EACH MIDAS CALL

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680 REM NS=STRING USED TO INPUT OPERATOR'S NAME
690 REM OS=INPUT STRING SPECIFYING PHYSICAL ADDRESS
700 REM O2S=STRING USED TO INPUT TEST NO.
710 REM P=FREQUENCY INPUT (KHZ)
720 REM R=RANGE OF STD. TE
730 REM R0=VARIABLE SELECTS RELAY OPERATION
740 REM HV RELAYS. E-MODULE. R0=1..CLOSE DCR RELAY
750 REM R0=2..CLOSE AC RELAY
760 REM R0=3..CLOSE DC RELAY
770 REM R0=11..OPEN DCR RELAY
780 REM R0=12..OPEN AC RELAY
790 REM R0=13..OPEN DC RELAY
800 REM K-MODULE. R0=3, CLOSE EH. R0=2, CLOSE EL RELAY.
810 REM R0=4..CLOSE SET RELAY
820 REM R0=5..CLOSE READ RELAY
830 REM R0=13, OPEN EH. R0=12, OPEN EL RELAY.
840 REM R0=14..OPEN SET RELAY
850 REM R0=15..OPEN READ RELAY
860 REM R0=0..OPEN ALL RELAYS
870 REM R0S=RANGE SELECT FOR AC SOURCE
880 REM RS=CHARACTER STRING REFERENCE USED FOR RELAY OPERATION
890 REM S=COUNTER FOR RANGE
900 REM S1=STD. DEV. OF AN OBS. FOR
901 REM 4 OR MORE DETERMINATIONS
910 REM S2=POOLED EST. OF TEST S.D. OF MEAN
920 REM T=DECISION POINT VARIABLE
930 REM T0=TIME DELAY LOOP VARIABLE
940 REM TS=OUTPUT FORMAT
950 REM VS=STRING OUTPUT FROM MIDAS
960 REM VOS=STRING INPUT TO SET VOLTAGE
961 REM ON BOTH AC & DC SOURCES
970 REM V=NUMERIC VALUE OF VS
980 REM W=DIVISOR IN AVE. CALC.
990 REM X,X1,X2,X5,X6,X7=ALL USED IN S.D.T.
1000 REM Y=USED IN Y1 CALC.
1010 REM Y1=STD. DEV. OF 10 DLA READINGS
1020 REM Z=COUNTER OF Y1'S Z=5=ABORT
1030 DIM O2S(6),IS(20),DS(15),NS(25)
1040 ;"INPUT CURRENT DATE,YOUR NAME,TEST NO. ,AND TEST INST."
1050 ;" "
1060 INPUT DS,NS,O2S,IS
1070 ; ON (6)"DATE.....",DS
1080 ; ON (6)
1090 ; ON (6)"OBSERVER.....",NS
1100 ; ON (6)
1110 ; ON (6)"TEST NO.....",O2S
1120 ; ON (6)
1130 ; ON (6)"INST.....",IS
1140 ; ON (6)
1150 ; ON (6)
1160 ; ON (6)" APP TEST STANDARD ES ET X"
1170 ; ON (6)" V RANGE TE RANGE MV MV"
1180 DIM F0S(2),F1S(2),R0S(1),R1S(1),V0S(7),V1S(7),V2S(7)
1190 DIM C0S(3),CS(2),TS(72),BS(7,8),A(8,2)

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```

1200 S=0
1210 J=0
1220 D=0
1230 M0=38
1240 Z=0
1250 H=0
1260 L=0
1270 X7=0
1280 W=0
1290 FOR I=1 TO 8
1300 READ BS(I),A(I,1),A(I,2)
1310 NEXT I
1320 DATA "F1",1.98,.39E-1
1330 DATA "F2",2.03,.28E-1
1340 DATA "FG",2.04,.31E-1
1350 DATA "FC",1.9,.32E-1
1360 DATA "FH",2.02,.32E-1
1370 DATA "FA",2.03,.42E-1
1380 DATA "FB",1.94,.14E-1
1390 DATA "FD",2.03,.42E-1
1400 DIM VS(12),OS(29),RS(16)
1410 VS=" "
1420 RS="776>5=4<3;2:1908"
1430 T0=1800
1440 ;" "
1450 ;"INPUT TEST VOLTAGE,TEST RANGE,STD. RANGE"
1460 INPUT A,B,R
1470 IF S=0 GOTO 1500
1480 GOSUB 5970
1490 GOSUB 6060
1500 GOSUB 4640
1510 GOSUB 3420
1520 ;" "
1530 ;"SET COMP. TO E-HIGH, POT 'R OFF,DLA 10 MV,GND OFF"
1540 ;"TO CONTINUE, RETURN"
1550 INPUT G
1560 L=L+1
1570 R0=3
1580 GOSUB 5690
1590 R0=4
1600 GOSUB 5800
1610 GOSUB 6170
1620 FOR I9=1 TO 1600
1630 NEXT I9
1640 GOSUB 5400
1641 ;"INPUT THE CODE FOR STANDARD 'TE' (IN QUOTES)"
1642 ;" "
1643 INPUT CS
1644 FOR I=1 TO 8
1645 IF BS(I)<>CS THEN 1648
1646 IO=I
1647 I=100
1648 NEXT I
1649 IF I>=100 THEN 1653
1650 ;"STANDARD NOT FOUND; TRY AGAIN"
1651 ;" "

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1652 GOTO 1641
1653 M=A(10,1)
1654 N=A(10,2)
1655 E=V*1000
1660 ;"E-HIGH    -",E,"MILLIVOLTS"
1670 ;"CHANGE 'BB' TO E-LOW, THEN RETURN  "
1680 INPUT G
1690 GOSUB 5400
1700 E9=V*1000
1710 ;"E-LOW    =",E9,"MILLIVOLTS"
1712 IF E>E9 THEN 1720
1714 ;" "
1716 ;"E-LOW IS GREATER THAN E-HIGH, SWITCH CONNECTIONS"
1718 GOTO 5910
1720 TS="000000000000.0 000.0 00 000.0 00.0 00.0 00.00"
1730 ; ON (6)
1740 ;" "
1750 ;"IF";CS;" IS E-HIGH, INPUT '1'. IF NOT, INPUT '0'."
1760 INPUT G
1770 IF G=0 GOTO 1810
1780 K=E9*(M-E*N)
1790 ; ON (6) USING TS,A,B,CS,R,E,E9,K
1800 GOTO 1940
1810 K=E9*(M-E9*N)
1820 ; ON (6) USING TS,A,B,CS,R,E9,E,K
1830 ;" "
1840 ;"SET COMPARATOR TO E-HIGH. RETURN"
1850 INPUT G
1940 ;"POT 'R ON  - SET DLA 10 MICRO-VOLTS  - SET NULL,RETURN"
1950 ;" "
1960 INPUT G
1970 R0=14
1980 GOSUB 5800
1990 R0=5
2000 GOSUB 5800
2010 ;"BALANCE DIVIDER, THEN RETURN"
2020 ;" "
2030 INPUT G
2035 GOSUB 5970
2040 R0=15
2050 GOSUB 5800
2060 R0=13
2070 GOSUB 5690
2080 R0=4
2090 GOSUB 5800
2110 ; ON (6)
2120 ; ON (6)"  KHZ      COR      AC-DC DIFFERENCE
2130 ; ON (6)"  STD      AVE T"
2140 ; ON (6)"      PPM
2150 ; ON (6)"DEV      COR PPM"
2160 ; ON (6)
2170 X=0
2180 X1=0
2190 X2=0
2200 C=0
2210 W=0

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2220 ;" INPUT FREQUENCY (KHZ)"
2230 ;"  "
2240 INPUT P
2250 IF R<100 THEN C=0
2260 IF R=100 THEN C=-(P^2/1000)
2270 IF R=200 THEN C=-(P^2/1000)
2280 IF R=300 THEN C=(P^2/1000)^1.5
2290 IF R=600 THEN C=(P^2/1000)^1.3
2300 IF R=1001 THEN C=(P^2/100)*2-P
2310 IF R=1002 THEN C=P^2*.12E-1
2320 C=INT(C)
2330 R0=3
2340 T=3
2350 GOSUB 5690
2360 GOSUB 6170
2370 ;"  "
2380 R0=4
2390 GOSUB 5800
2400 ;" SET POT NULL, THEN RETURN"
2410 INPUT G
2420 GOSUB 5970
2430 R0=13
2440 GOSUB 5690
2445 GOSUB 6060
2450 R0=2
2460 GOSUB 5690
2470 GOSUB 6340
2480 FOR I9=1 TO 2000
2490 NEXT I9
2500 GOSUB 4000
2510 R0=14
2520 GOSUB 5800
2530 R0=5
2540 GOSUB 5800
2550 IF W<>0 THEN 2600
2560 ;"WAIT FOR DLA TO STOP DRIFT."
2570 ;"REBALANCE DIVIDER IF NECESSARY, THEN RETURN."
2580 ;"  "
2590 INPUT G
2600 FOR I9=1 TO T0
2610 NEXT I9
2620 GOSUB 5500
2630 E1=V*.1E10
2640 ;"E1      =",E1,"NANOVOLTS"
2650 FOR I0=1 TO 4
2660 GOSUB 6060
2670 R0=12
2680 GOSUB 5690
2690 R0=3
2700 GOSUB 5690
2710 GOSUB 6170
2720 FOR I9=1 TO T0
2730 NEXT I9
2740 GOSUB 5500
2750 E2=V*.1E10

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2760 ;"E2          =" ,E2,"NANOVOLTS"
2770 GOSUB 5970
2780 R0=13
2790 GOSUB 5690
2800 R0=1
2810 GOSUB 5690
2820 GOSUB 6170
2830 FOR I9=1 TO T0
2840 NEXT I9
2850 GOSUB 5500
2860 E3=V*.1E10
2870 ;"E3          =" ,E3,"NANOVOLTS"
2880 GOSUB 5970
2890 R0=11
2900 GOSUB 5690
2910 R0=2
2920 GOSUB 5690
2930 GOSUB 6340
2940 R0=5
2950 GOSUB 5800
2960 FOR I9=1 TO T0
2970 NEXT I9
2980 GOSUB 5500
2990 E4=V*.1E10
3000 ;"E4          =" ,E4,"NANOVOLTS"
3010 A0(I0)=(-E1+E2+E3-E4)/(2*K)
3020 IF I0=4 THEN 3050
3030 E1=E4
3040 ;"E1          =" ,E1,"NANOVOLTS"
3050 NEXT I0
3060 W=W+4
3070 X=X+A0(1)^2+A0(2)^2+A0(3)^2+A0(4)^2
3080 X1=X1+A0(1)+A0(2)+A0(3)+A0(4)
3090 B1=A0(1)+A0(2)+A0(3)+A0(4)
3100 B1=B1/4
3110 B0=X1/W
3115 P0=(X1/W)+(C)
3120 X2=B0*X1
3130 S1=SQR((X-X2)/(W-1))
3140 TS(1,50)="000.00      -00      (-0000 -0000 -0000 -0000)
3150 TS(51,72)=" 000.0    -0000.0 "
3160 ; ON (6) USING TS,P,C,A0(1),A0(2),A0(3),A0(4),S1,P0
3170 H=H+4
3180 X6=0
3190 FOR J1=1 TO 4
3200 X5=(A0(J1)-B1)^2
3210 X6=X6+X5
3220 NEXT J1
3230 X7=X7+X6
3240 ;"REPEAT,FREQUENCY,RANGE,STOP,REPEAT W/O AVE. ?"
3250 ;" 1          2          3          4          5 "
3260 ;" "
3270 INPUT T
3275 GOSUB 6060
3280 IF T=4 THEN 5200

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3290 M1=0
3300 OS="<35>E89:;<=>?K89:;<=>?"
3310 CALL 1,M0,OS,VS,M1,M2
3320 IF T=1 THEN 2330
3330 IF T=2 THEN 1510
3340 IF T=3 THEN 3360
3350 IF T=5 THEN 3380
3360 S=1
3370 GOTO 1450
3380 X7=X7-X6
3390 H=H-4
3400 ; ON (6)"ABOVE DATA DELETED FROM TEST"
3410 GOTO 2160
3420 GOSUB 6060
3430 ;
3440 ;"          AC VOLTAGE SET          "
3450 ;"*****IMPORTANT NOTE*****"
3460 ;"WHEN SETTING AN AC VOLTAGE OF 1,10,OR 100 VOLTS, YOU MUST"
3470 ;"CHOOSE THE MAX. OUTPUT OF THE CORRESPONDING RANGE, FOR EXAMPLE"
3480 ;"WHEN APPLYING 10 V YOU MUST PROGRAM 5-NINES (99999) ON THE 10 V"
3490 ;"RANGE, AND NOT(REPEAT NOT) 10000 ON THE 100 V RANGE"
3500 ;
3510 ;
3520 ;"THE FREQUENCY IS CODED IN TWO DIGITS.  THE FIRST DIGIT MUST BE"
3530 ;"A NUMBER FROM 1 TO 11, MEANING THE HIGH ORDER DIGIT.  THE"
3540 ;"SECOND DIGIT ARE MULTIPLES OF 10, STARTING WITH 0=X10 AND"
3550 ;"3 = X10 K.  IN HEX- A TEN IS A':' AND A ELEVEN IS A';'."
3560 ;
3570 ;"  "
3580 ;"INPUT FREQUENCY"
3590 INPUT F0$
3600 F1$=F0$
3610 ;
3620 D=1
3630 R0$="6"
3640 GOSUB 6420
3650 D=0
3660 ;"TO SET VOLTAGE AND RANGE, FIRST INPUT THE CORRECT RANGE"
3670 ;"FOLLOWED BY THE 5-DIGIT VOLTAGE.  A RANGE OF 0 = 1MV, 1 = 10MV,"
3680 ;"2 = 100MV , 3 = 1V , 4 = 10V , 5 = 100V ,AND 6 = 1000V."
3682 ;" WHEN TEST LO & HI AC MUST SET RANGE TO NEXT"
3684 ;" HIGHEST RANGE LIMIT FROM TEST VOLTAGE"
3686 ;" (EX. 1 - TEST 4 V AC SET RANGE AT 4=10V OR"
3688 ;" EX. 2 - TEST 100 V AC SET RANGE AT 6=1000)."
3690 ;
3700 ;"  "
3710 ;"INPUT RANGE,VOLTAGE"
3720 INPUT R0$,V0$
3730 R1$=R0$
3740 V2$=V0$
3750 IF R0$="6" GOTO 3820
3760 OS="<35>CP"+V0$(1,5)+R0$+F0$+"02"
3770 CALL 1,M0,OS,VS,M1,M2
3780 M1=1
3790 OS="<35>F0"

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3800 CALL 1,M0,0S,VS,M1,M2
3810 GOTO 3880
3820 OS="<35>CP"+V0S(1,5)+R0S+F0S+"20"
3830 ;
3840 ;"CONNECT HIGH VOLTAGE AMP.,THEN RETURN"
3850 ;" "
3860 INPUT G
3870 GOTO 3770
3880 ;"CHECK AC VOLTAGE AND FREQUENCY,IF CORRECT INPUT '1',
3890 ;"THEN RETURN. IF INCORRECT,INPUT '2',THEN RETURN."
3900 ;" "
3910 INPUT A5
3920 IF A5=1 GOTO 3940
3930 GOTO 3420
3940 ;"IF FREQ. CHANGE INPUT '1',IF RANGE OR INITIAL RUN,RETURN"
3950 ;" "
3960 INPUT A6
3970 IF A6=1 GOTO 2160
3980 IF R0S="6" GOTO 6060
3990 RETURN
4000 ;"AC VOLTAGE CHECK"
4010 R0=2
4020 GOSUB 5690
4030 GOSUB 5400
4040 ;V
4050 A2=V
4060 A2=A2*.1E9
4070 V=V*.1E9
4080 IF ABS(A2)<100 THEN 4600
4090 IF VS(1,1)="-" THEN 4350
4100 IF R0S="4" THEN 4140
4110 IF R0S="5" THEN 4140
4120 IF R0S="6" THEN 4140
4130 GOTO 4150
4140 IF V0S(1,1)="9" THEN 4170
4150 C7=3
4160 GOTO 4180
4170 C7=40
4180 A2=VAL(V0S)
4190 A2=A2-C7
4200 V0S=STRS(A2)
4210 M1=0
4220 IF R0S="6" GOTO 4290
4230 OS="<35>CP"+V0S(1,5)+R0S+F0S+"02"
4240 CALL 1,M0,0S,VS,M1,M2
4250 M1=1
4260 OS="<35>F0"
4270 CALL 1,M0,0S,VS,M1,M2
4280 GOTO 4310
4290 OS="<35>CP"+V0S(1,5)+R0S+F0S+"20"
4300 GOTO 4270
4310 FOR I8=1 TO 1500
4320 NEXT I8
4330 GOSUB 5400
4340 GOTO 4040

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4350 IF R05="4" THEN 4390
4360 IF R05="5" THEN 4390
4370 IF R05="6" THEN 4390
4380 GOTO 4400
4390 IF V05(1,1)="9" THEN 4420
4400 C7=3
4410 GOTO 4430
4420 C7=40
4430 A2=VAL(V05)
4440 A2=A2+C7
4450 V05=STR5(A2)
4460 M1=0
4470 IF R05="6" GOTO 4540
4480 OS="<35>CP"+V05(1,5)+R05+F05+"02"
4490 CALL 1,M0,OS,VS,M1,M2
4500 M1=1
4510 OS="<35>F0"
4520 CALL 1,M0,OS,VS,M1,M2
4530 GOTO 4560
4540 OS="<35>CP"+V05(1,5)+R05+F05+"20"
4550 GOTO 4520
4560 FOR I8=1 TO 1500
4570 NEXT I8
4580 GOSUB 5400
4590 GOTO 4040
4600 R0=2
4610 V=V/.1E9
4620 GOSUB 5690
4630 RETURN
4640 ;"
4650 VS="
4660 ;
4670 ;"TO SET THE VOLTAGE RANGE AND TRIP, INPUT FIRST THE CORRECT"
4680 ;"RANGE FOLLOWED BY A COMMA AND THE DESIRED VOLTAGE. RANGES"
4690 ;"OF 10, 100, AND 1000 ARE ALLOWED. VOLTAGE MUST BE 7 DIGITS."
4695 ;" WHEN TEST AT LO V (<=100 V DC) MUST SET RANGE AT 1000."
4700 ;
4710 ;" INPUT RANGE,VOLTAGE"
4720 ;" "
4730 M0=38
4740 M1=0
4750 INPUT R1,V05
4760 R2=R1
4770 VIS=V05
4780 IF R1=10 GOTO 4990
4790 IF R1=100 GOTO 5030
4800 IF R1=1000 GOTO 5070
4810 GOTO 4710
4820 OS="<35>DP"+V05+" ;"+C05
4830 CALL 1,M0,OS,VS,M1,M2
4840 M1=1
4850 OS="<35>F0"
4860 CALL 1,M0,OS,VS,M1,M2
4870 VS(2,2)=" "
4880 ;VS

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DC VOLTAGE SET "

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4890 IF VAL(VS)<=6 THEN 5110
4900 ;"CHECK DC VOLTAGE, IF CORRECT INPUT '1', THEN RETURN."
4910 ;"IF INCORRECT, INPUT '2', THEN RETURN"
4920 ;" "
4930 INPUT A4
4940 IF A4=1 GOTO 4950
4945 IF A4=2 GOTO 5130
4950 GOTO 5970
4960 RETURN
4970 GOTO 4640
4980 RETURN
4990 COS="840"
5000 OS="<35>DP0000000;;"+COS
5010 CALL 1,M0,OS,VS,M1,M2
5020 GOTO 4820
5030 COS="942"
5040 OS="<35>DP0000000;;"+COS
5050 CALL 1,M0,OS,VS,M1,M2
5060 GOTO 4820
5070 COS="=41"
5080 OS="<35>DP0000000;;"+COS
5090 CALL 1,M0,OS,VS,M1,M2
5100 GOTO 4820
5110 ;"WARNING - SYSTEM TRIPPED, SUPPLY AUTOMATICALLY RESET"
5120 ;" TRY AGAIN."
5130 M1=0
5140 VOS="0000000"
5150 COS="000"
5160 OS="<35>DP"+VOS+"00"+COS
5170 CALL 1,M0,OS,VS,M1,M2
5180 GOTO 4640
5190 RETURN
5200 ;"DO YOU WANT STATISTICS PRINTOUT?"
5210 ;"IF YES,ENTER '1' AND RETURN"
5220 ;"IF NOT ,ENTER '2' AND RETURN"
5230 ;" "
5240 INPUT T
5250 IF T=2 THEN 5910
5260 D1=H-L
5270 S2=SQR((X7/D1)/(H/L))
5280 ; ON (6)
5290 ; ON (6)"NUMBER OF READINGS=H=.....",H
5300 ; ON (6)
5310 ; ON (6)"NUMBER OF INDEP. TESTS=L=..",L
5320 ; ON (6)
5330 ; ON (6)"DEGREES OF FREEDOM=D1=.....",D1
5340 ; ON (6)
5350 ; ON (6)"POOLED ESTIMATE OF TEST STD. DEV. OF MEAN=S2"
5360 ; ON (6)"=S.D.T.(SEE S.P. 300,V.1, P. 316-40).....",S2
5370 ; ON (6)
5380 ; ON (6)"3*S.D.T.=.....",3*S2
5390 GOTO 5910
5400 M1=12
5410 OS="<35>BTTU<17>"

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5420 CALL 1,M0,0S,VS,M1,M2
5430 VS(LEN(VS)+1,LEN(VS)+1)=" "
5440 IF VS(2,2)=":" THEN 5480
5450 IF VS(2,2)=":" THEN 5480
5460 V=VAL(VS)
5470 RETURN
5480 V=2000
5490 RETURN
5500 Y=0
5510 Y1=0
5520 FOR K0=1 TO 10
5530 GOSUB 5400
5540 Y=Y+V
5550 Y1=Y1+V*V
5560 NEXT K0
5570 Y1=SQR((Y1-(Y*Y/10))/9)
5580 IF Y1*.1E10<200 THEN 5660
5590 ;"STD. DEV.  =",Y1*.1E10,"NANOVOLTS"
5600 Z=Z+1
5610 IF Z=5 THEN 5630
5620 GOTO 5500
5630 ;"WARNING-JOB ABORTED, TESTS EQUAL FIVE, SYSTEM UNSTABLE"
5640 ;" "
5650 GOTO 5910
5660 V=Y/10
5670 Z=0
5680 RETURN
5690 R0=INT(R0)
5700 IF R0>=0 AND R0<19 THEN 5730
5710 ;"INVALID RELAY ADDRESS"
5720 RETURN
5730 M1=0
5740 R1=INT(R0/10)
5750 R2=INT(R0-R1*10)
5760 IF R0<>0 THEN OS="<35>E"+RS(2*R2-1+R1,2*R2-1+R1)
5770 IF R0=0 THEN OS="<35>E89:;<=>?"
5780 CALL 1,M0,0S,VS,M1,M2
5790 RETURN
5800 R0=INT(R0)
5810 IF R0>=0 AND R0<19 THEN 5840
5820 ;"INVALID RELAY ADDRESS"
5830 RETURN
5840 M1=0
5850 R1=INT(R0/10)
5860 R2=INT(R0-R1*10)
5870 IF R0<>0 THEN OS="<35>K"+RS(2*R2-1+R1,2*R2-1+R1)
5880 IF R0=0 THEN OS="<35>K89:;<=>?"
5890 CALL 1,M0,0S,VS,M1,M2
5900 RETURN
5910 R0=0
5940 J=1
5950 R0=0
5960 Z=0
5970 M1=0

```

```

5980 V0S="0000000"
5990 C0S="000"
6000 OS="<35>DP"+V0S+"00"+C0S
6010 CALL 1,M0,OS,VS,M1,M2
6020 IF J=1 GOTO 6080
6030 V0S=V1S
6040 R1=R2
6050 RETURN
6060 M1=0
6070 V0S="0000000"
6080 R0S="0"
6090 F0S="00"
6100 OS="<35>CP"+V0S(1,5)+R0S+F0S+"00"
6110 CALL 1,M0,OS,VS,M1,M2
6114 GOSUB 5690
6120 IF J=1 GOTO 6640
6130 R0S=R1S
6140 V0S=V2S
6150 F0S=F1S
6160 RETURN
6170 M0=38
6180 M1=0
6190 C0S="=41"
6200 OS="<35>DP00000000;;"+C0S
6210 CALL 1,M0,OS,VS,M1,M2
6220 V0S=V1S
6230 R1=R2
6240 FOR I9=1 TO 100
6250 NEXT I9
6260 OS="<35>DP"+V0S+";;"+C0S
6270 CALL 1,M0,OS,VS,M1,M2
6280 M1=1
6290 OS="<35>F0"
6300 CALL 1,M0,OS,VS,M1,M2
6310 R2=R1
6320 V1S=V0S
6330 RETURN
6340 M1=0
6350 V0S="0000000"
6360 R0S="0"
6370 F0S="00"
6380 OS="<35>CP"+V0S(1,5)+R0S+F0S+"00"
6390 CALL 1,M0,OS,VS,M1,M2
6400 R0S=R1S
6410 F0S=F1S
6420 V0S="10500"
6430 FOR I9=1 TO 100
6440 NEXT I9
6450 OS="<35>CP"+V0S(1,5)+R0S+F0S+"20"
6460 CALL 1,M0,OS,VS,M1,M2
6470 M1=1
6480 OS="<35>F0"
6490 CALL 1,M0,OS,VS,M1,M2

```

```
6500 FOR I9=1 TO 150
6510 NEXT I9
6520 M1=0
6530 IF D=1 GOTO 6630
6540 V0S=V2S
6550 OS="<35>CP"+V0S(1,5)+R0S+F0S+"20"
6560 CALL 1,M0,OS,VS,M1,M2
6570 M1=1
6580 OS="<35>F0"
6590 CALL 1,M0,OS,VS,M1,M2
6600 FIS=F0S
6610 RIS=R0S
6620 V2S=V0S
6630 RETURN
6640 GOSUB 5800
6650 END
```



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| 16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)<br><br>A semiautomatic ac/dc difference calibration system is described. The system operates over a frequency range of 20 Hz to 100 kHz, covering the voltage range from 0.5 V to 1 kV. For all voltages at frequencies in the range from 20 Hz to 20 kHz, the total uncertainty is 50 parts per million (ppm), and 100 ppm for voltages at frequencies between 20 kHz and 100 kHz. In addition to ac/dc difference testing, the system can be readily adapted to calibrate precision ac digital voltmeters or ac calibrators. Results of extensive intercomparison testing of the new system against a manual test system are reported, using a multirange thermal transfer instrument as a transport standard. The results indicate that the ac/dc differences measured are well within the combined total uncertainty limits of the two systems. |   |  |                                    |
| 17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)<br>ac/dc difference; ac voltage measurement; automation; calibration; metrology; thermal voltage converter.   |   |  |                                    |
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